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Spatial and Temporal Variation in Water Quality Along an Urban Stretch of the Chattahoochee River and Utoy Creek in Atlanta, Georgia, 2013

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by

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ABSTRACT

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Spatial and Temporal Variations in Water Quality Along an Urban Stretch of the Chattahoochee River and Utoy Creek in Atlanta, Georgia, 2013
(Under the direction of Dr. Lisa Casanova, Faculty Member)

The Chattahoochee River is the most utilized surface water in Georgia, and it and Utoy Creek are receiving waters for Atlanta stormwater and wastewater effluent. Population growth and record-breaking rainfall in 2013 has led to potential stress from stormwater runoff and nonpoint source loading.

The goals of this research are to examine spatial and temporal variations in *E. coli* and the bacteriophage MS2 and relationships with DO, turbidity, rainfall, and riverflow; to determine if *E. coli* in water is correlated with *E. coli* in sediment; and to determine if wastewater effluent discharges influence downstream sample sites. Water samples were collected at fifteen sample sites and two outfall sites in the Chattachoochee, and ten sites in Utoy Creek. No significant spatial variation in *E. coli* was found for the Chattahoochee, although there was significant temporal variation in mean *E. coli* concentrations. The lowest mean DO values and the highest mean turbidity levels both occurred on the date of the highest mean *E. coli* concentrations. Effluent from the two outfalls did not contaminate downstream sample sites. In Utoy Creek, *E. coli* concentrations showed spatial and temporal variation in water samples, but not for sediment samples. Turbidity was found to be positively correlated with both *E. coli* in sediment and MS2.

These findings suggest that nonpoint source loading is a potential cause of contamination. Since DO, turbidity, and rainfall were correlated with *E. coli* and MS2, these parameters could be used as indicators of pollution for future monitoring of the Chattahoochee River and Utoy Creek.

Index Words: *E. coli*, MS2, Dissolved Oxygen, Turbidity, Chattahoochee River, Utoy Creek

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AUTHOR'S STATEMENT

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CHAPTER I

INTRODUCTION

1.1 Background

The Chattahoochee River stretches 434 miles and flows through Georgia, specifically through metropolitan Atlanta, and Alabama before terminating in Florida's Lake Seminole (EPD, 1997). Five miles above the mouth of the Chattahoochee River Basin exists a 34 square mile watershed, Utoy Creek, which flows directly into the Chattahoochee River (EPA, 2003). Both of these surface waters are of extreme importance for the city of Atlanta and the surrounding highly urbanized areas. For instance, the Chattahoochee River is the most utilized surface water source for drinking water in the entire state of Georgia, supplying more than seventy percent of metro Atlanta's water needs (EPD, 1997). The Chattahoochee River also assimilates much of metro Atlanta's municipal wastewater discharge (EPD, 1997). Utoy Creek is important since it serves as the receiving waters for multiple stormwater outfalls and water reclamation centers (EPA, 2003). Thus, due to Atlanta's dependence on the Chattahoochee River and Utoy Creek, monitoring and maintaining the integrity of these surface waters is of great importance.

Since Atlanta is an older city, its corresponding sanitary sewer system, built in the 1880s, has issues with cracked and leaking pipes that are only built to handle the volume from the city's sanitary sewage (Clean Water Atlanta, 2010). Thus, with the growing population, not only was there an increase in the amount of sanitary sewage in the system, but also a tremendous increase in the amount of stormwater, of which the system was not intended to handle. As a result, the strained capacity of the sanitary sewer system led to sanitary sewer overflow (SSO) events, during which a mixture of untreated sewage, groundwater, and stormwater was overflowing from pipes and manholes, many of which are located within close proximities to creeks and streams (Clean Water Atlanta, 2010).

In response to the growing concern of the poor water quality of the Chattahoochee River, as well as Atlanta's dependence on it as a critical water source, several federal and state laws, such as the Federal Clean Water Act, Safe Drinking Water Act and the State Water Quality Control Act, were instituted to protect its water quality by defining and monitoring definitive water quality standards for the health of the consumers (EPD, 1997). In 1995, Atlanta began a massive program, the Consent Decree, to improve the city's four Water Reclamation Centers (WRCs) in order to comply with state regulations and legislative mandates set by the previously mentioned federal and state laws. In fact, the Consent Decree was established as a result of the city of Atlanta being sued for violating the Clean Water Act. Specifically, the Consent Decree was intended to improve the water quality in the downstream receiving waters, such as the Chattahoochee, by improving the water quality of the effluent discharged from the WRCs (Clean Water Atlanta, 2010). To overcome the issues caused by SSO events, the city of Atlanta, the Environmental Protection Agency (EPA) and the Environmental Protection Division (EPD) negotiated a settlement called the First Amended Consent Decree (FACD), which evaluates and improves measures to eliminate SSOs and upgrade the WRCs, with the ultimate long-term goal of eliminating groundwater and stormwater entering the system altogether. The FACD builds on the programs already put in place by the city of Atlanta, which uses closed-circuit television to inspect and assess the condition of the sewers, intensifies review of building permit applications that propose adding new flows into the sewer system, and manages plans to operate the collection system more effectively (Clean Water Atlanta, 2010). Finally, in July 2001, the federal

EPA and state EPD authorized the city of Atlanta to implement a plan to eliminate water quality violations from Combined Sewer Overflows (CSOs). According to this plan, as parts of the combined sewer system are separated, the same system can be used to treat stormwater runoff from the urban portion of the CSO area. A further refined plan was authorized in June 2003 to increase the city's total separation area from 85% to 90%, eliminate two CSO facilities, construct a deep rock tunnel storage and treatment system to capture and store combined stormwater and sewage flow for conveyance to two new CSO treatment facilities before discharge into the Chattahoochee. As a result, the number of CSO events should be reduced from more than sixty annually at six existing facilities to an average of four annually at four remaining facilities. Furthermore, the remaining overflows will be screened, disinfected, dechlorinated, and will meet water quality standards before discharge into the Chattahoochee (Clean Water Atlanta, 2010).

With the establishment of these federal and state laws, water quality in the Chattahoochee River basin is now considered to be generally good as wastewater discharges have been under strict control (EPD, 1997). The determination of factors affecting water quality is still of utmost importance. For instance, previous management of the river focused on point sources from municipal or industrial water pollution control facilities, but nonpoint sources of pollution through stormwater are now affecting the Chattahoochee River. Furthermore, growth in population along the surrounding metro Atlanta areas will likely lead to more potential stress from stormwater runoff and nonpoint source loading. For instance, as a watershed becomes more developed, impervious surfaces prevent rainfall from infiltrating the ground, resulting in increased stormwater runoff, flooding and stream bank erosion.

An interesting aspect to this present research opportunity is the fact that Atlanta experienced a record-breaking amount of rainfall during 2013. The city had the fifth wettest year on record with a total rainfall of 66.02 inches. In fact, the only years with more rainfall were 2009 (69.43 inches), 1948, 1935, and 1929. Atlanta had nearly 17 inches more than the average annual total, and this occurred without any big rains from a tropical storm (AJC, 2013). Specifically, Atlanta experienced the fourth wettest June in the city's history (9.57 inches and the record was in 1912 at 11.21 inches) (CBS Atlanta, 2013). According to the National Weather Service, Atlanta received more than 50.43 inches of rain as of mid-August, which is .75 inches more than the yearly average (NOAA, 2013). This amount of rainfall is of importance to environmental health researchers since previous studies have found a degradation in water quality could be explained by a recent flood event that significantly increased the pollutant load as a result of stormwater runoff, dissolution, and the resuspension of deposits. (Maane-Messai et al., 2010)

1.2 Purpose of the Study

First, contamination of *Escherichia coli*, a common bacteria found in the digestive system of humans and animals, are often indicative of fecal contamination and are used as an indicator of microbial pollution in water sources. Furthermore, the monitoring sewage effluents for only fecal indicator bacteria (FIB) such *E. coli* may not adequately detect viral contamination, which is the reason that MS2, a bacteriophage linked in high proportions to wastewater samples, could reflect the impact of urbanization on surface water samples (Cole, Long, & Sobsey, 2003). Second, spatial (longitudinal) variation in *E. coli* and MS2 in rivers and creeks is of great importance since it helps to identify sources of fecal pollution prior to establishing water quality monitoring plans. Thirdly, temporal variation in *E. coli* contamination of rivers could be a direct result of weather-related changes such as an event, temperature, and river flow. In addition, temporal variation could be an indirect result of increased recreational activities and discharges of treated wastewater effluent. Finally, despite the attention brought on by the federal and state regulations, few investigations have been published concerning the water quality of the Chattahoochee River and Utoy Creek.

1.3 Research Questions

The specific research questions to be analyzed in this study are as follows:

- Are there spatial and temporal variations in *E. coli* and MS2 concentrations along the Chattahoochee River and the Utoy Creek sample sites?
- Are the concentrations of *E. coli* and MS2 correlated with dissolved oxygen (DO), turbidity, rainfall, and riverflow?
- Are the concentrations of *E. coli* correlated with the presence of MS2?
- From the Utoy Creek samples, are the concentrations of *E. coli* in the sediment correlated with the concentrations of *E. coli* in the water?
- Does the discharge of effluent from the Camp Creek Outfall and the Douglas County Outfall into the Chattahoochee River affect the concentrations of *E. coli* downstream?

CHAPTER II

REVIEW OF THE LITERATURE

2.1 Spatiotemporal Variation from Urbanization and Pollution

Several studies have been devoted to understanding the spatial and temporal variations within surface waters, with the ultimate goal of understanding not only point and nonpoint sources of contamination, but also for detecting trends in spatiotemporal variation that could be generalizeable to surface waters on a global scale. Urban wastewater has been found to be an important source of contamination associated with decreased quality of surface waters. Astrom et al. found that effluents from secondary wastewater treatment plants constituted a major source of microbial contamination within a river used as a raw water supply, and that inhibition of raw water intake could lower the health risk for consumers in this area. Specifically, the authors discovered correlations between discharges such as combined sewer overflows (CSOs) and peaks in fecal indicator concentrations, even from a single emergency discharge of untreated water (Astrom, Pettersson, Stenstrom, & Bergstedt, 2009). A recent study on a river system in central Chile discovered that water quality was poor at areas downstream of wastewater discharges, whereas the upstream quality was considered to be good (Debels, Figueroa, Urrutia, Barra, & Niell, 2005). Among a river basin system in central Portugal, contamination along the middle section of the river was attributed to urban wastewater discharges occurring within close proximity to one of the larger urban centers (Ferreira, Cerqueira, de Melo, de Figueiredo, & Keizer, 2010). A similar finding within an urban portion of an Algerian river found that the downstream portion of the river had a pollutant load almost twice as high as the upstream portion. Further investigation discovered that the downstream portion was subject to urban inputs of wastewater, which constitute 75% of the total volume, and the direct discharge of domestic waters are the sources of microbial and pathogenic contamination. In their concluding thoughts, the authors suggest that spatial variation within this river could be determined by the intensity and variety of the anthropic loads (Maane-Messai, Laignel, Motelay-Massei, Madani, & Chibane, 2010). An interesting study comparing the effects of sewage discharge versus stormwater found that surface waters contaminated with CSOs had a higher percentage of strains from human sources similar to sewage influent than did river water contaminated with stormwater only (McLellan, 2004). Finally, Rijal et al. concluded that pathogens found in the Chicago Area Waterway System (CAWS) of the water reclamation plant (WRP) were a result of CSOs and other discharges (Rijal et al., 2009).

Not only are urban wastewaters associated with microbial contamination, but literature also provides evidence of an association between surface water contamination and urban activity. For example, Brion et al. determined that areas of urban activity were more likely to recover F+ phages during rainfall events when compared to agricultural site (Brion, Meschke, & Sobsey, 2002). A study on tidal creeks along the southeastern United States revealed the following key findings: concentrations of indicator microorganisms were highest in more developed watersheds, fecal coliform concentrations were significantly lower in forested creeks when compared to urban and suburban creeks, F+ coliform concentrations were significantly higher in urban creeks when compared to suburban and forested creeks, the only human source of contamination was from an urban creek, and the strongest predictive relationship between bacterial and viral indicators occurred with increasing urbanization due to the fact that pollution was highest in more developed watersheds (DiDonato et al., 2009). A similar study of water sources in the southeastern United States determined that watersheds with the highest measure of urban land use and impervious surfaces had significantly greater fecal indicator bacteria (FIB) concentrations (Rowny & Stewart, 2012). A study by Ibekwe et al. concluded that more *E. coli* with resistance to antimicrobiologic agents were found in water samples from urban sources than from agricultural sources, and that a major cause of this pollution in coastal waters was a result of urban runoff into the rivers and storm drains (Ibekwe, Murinda, & Graves, 2011).

Determining spatial variations in microbial and pathogenic contamination among surface water could also provide insight into the appropriate measures for source tracking techniques and sampling strategies. For instance, Quilliam et al. suggest that, since their findings prove that significant differences in *E. coli* contamination occurred five times more on the east side of the river compared with the west, monitoring sites should consider the fact that the side of the river from which samples are taken can determine the water quality classification (Quilliam et al., 2011). Also, DiDonato et al. helped increase increased knowledge into differences between microbial and viral indicators conclude that a more noticeable gradient existed for microbial indicators than viral indicators, suggesting that viruses can survive longer downstream (DiDonato et al., 2009).

Research into temporal variations in water quality are also important aspects to maintaining appropriate water quality standards so that influxes in microbial loading of surface waters can be predicted and controlled for. Weather-related events, specifically those researching the impact of rainfall, have become the primary focus when determining temporal variations in surface water quality. When considering temperature as a variable for variation in fecal contamination of surface water, several studies point to the findings of decreased water quality during the higher temperatures of summer and early fall (Debels et al., 2005; Ishii, Hansen, Hicks, & Sadowsky, 2007; Maane-Messai et al., 2010). Maane-Messai et al., who concluded that spatial variations in river quality are often determined by the intensity of anthropic load, also suggested that temporal variability of the water quality can be explained by climatic variations and mainly the variations in precipitation (Maane-Messai et al., 2010). Chase et al. found negative correlations between levels of fecal coliforms with duration since the last rain event (Chase, Hunting, Staley, & Harwood, 2012). Furthermore, when considering temporal changes in water volume inputs and water quality, a recent study determined a positive association between high levels of precipitation 2 and 4 weeks prior to infectious gastrointestinal illness-related clinic visits, as well as increased total coliform and *E.* coli counts in untreated water sources (Harper, Edge, Schuster-Wallace, Berke, & McEwen, 2011). A final important characteristic of temporal variation in water quality indicators is the fact that daily variations can occur. Wu et al. conducted a study in which they determined that *E. coli* densities exhibited extreme variation between daily samples, with a decrease from 1214 MPN/100mL to 545 MPN/100mL the very next day at the same sample site (Wu, Rees, & Dorner, 2011).

2.2 Weather-Related Events and Stormwater Runoff

In regards to increased rainfall, a recent study found that degradation in water quality could be explained by a recent flood event that significantly increased the pollutant load as a result of stormwater runoff, dissolution, and the resuspension of deposits (Maane-Messai et al., 2010). Rowny et al. found that microbial nonpoint source pollution in the Jordan Lake watershed was significantly influenced by antecedent precipitation (Rowny & Stewart, 2012). In regards to the timing of microbial variations, Bougeard et al. concluded not only that *E. coli* variations are linked to rainfall, but also that very high levels of *E. coli* are evident at the start of a rainfall event followed by decreased concentrations as the event progressed (Bougeard et al., 2011). However, a study conducted by Surbeck, et al. concluded that FIB increased by one order of magnitude at the onset of a storm event, but that the concentration of fecal pollution remained elevated throughout the course of the storm (Surbeck, Jiang, Ahn, & Grant, 2006). One study, which recovered F+ phages from 75% of wet weather samples, suggested that there is a relationship between rainfall and the presence of F+ phages from surface waters (Brion et al., 2002). When considering the amount of rainfall that contributes to contamination, Coulliette et al. found significant increases in fecal contamination after 2.54cm of rainfall when compared to no rainfall (Coulliette & Noble, 2008). Similar results were found in receiving waters in North Carolina where 9.5cm of rainfall increased FIB to levels above the EPA water quality standard in 30% of wells in close proximity to onsite water treatment systems (OWTS). (Habteselassie et al., 2011) Interestingly, Davies et al. found that F-specific RNA coliphages entering stormwater treatment systems reflected the intensity and frequency of rainfall, where they were only detected when rainfall was intense or prolonged (Davies, Yousefi, & Bavor, 2003). Similarly, Wu et al. also discovered that intense storms of short duration led to higher increases in *E.* coli densities than moderate storms of longer duration. Moreover, during dry weather, 68.8% of samples met appropriate water quality standards, whereas as only 32% of wet weather samples achieved this standard. The authors concluded that *E. coli* densities could increase as much as tenfold during wet weather events (Wu et al., 2011). Among sampling sites along the CAWS, a study revealed that fecal coliform concentrations were elevated during periods of light rainfall, and that no significant reductions were evident up to 72 hours past the wet weather event (Rijal et al., 2009).

Several studies have been conducted to provide insight into the possible pathways of contamination that link rainfall to surface water contamination, with several concluding that wastewater discharge is the most probable pathway. Within the study sites, a single emergency discharge of untreated wastewater resulting in a sewer overflow (SO) due to increased rain intensity in the catchment resulted in an increased density of pathogens. The authors specifically determined that a high density of pathogens in the surface water relates to microbial discharge events, which are also correlated with rain intensity in the catchment (Astrom et al., 2009). A similar study conducted on the CAWS concluded that the presence of pathogens downstream of the WRP were due to secondary loading of the waterway under wet weather conditions from CSOs and other discharges. Further investigation into this finding discovered that the frequency of detection of FIB and pathogens was higher surrounding the WRP than the outfall concentrations, primarily due to CSO discharge events (Rijal et al., 2009).

Not only is rainfall correlated with microbial loading of surface water through wastewater discharge events, but several studies have provided information that directly point to the presence of microbial contamination within the stormwater runoff itself. Brion et al. recovered F+ coliphages from 75% of wet weather samples of both urban and nonurban runoff (Brion et al., 2002). Coulliette et al., when studying the levels of microbial contamination of surface water after varying levels of rainfall, determined that not only does stormwater runoff adversely impact water quality, but also that rainfall is a significant factor in the contribution of fecal contamination through stormwater runoff (Coulliette & Noble, 2008). A study of the Menomonee River revealed similar results, where stormwater contributed a major fecal bacterial load even in the absence of a CSO event since the *E. coli* concentrations ranged from 100 to greater than 240,000 CFU/100mL among the five major stormwater outfall sites. In fact, *E.* coli levels at sample sites impacted by a CSO event did not exceed levels found at samples sites impacted only by stormwater. More importantly, this study provided evidence for human sources of fecal contamination in stormwater in the absence of sewer overflows (Salmore, Hollis, & McLellan, 2006). A study providing similar results among six stormwater sites also found sewage associated markers in all stormwater sampling sites, typically by orders of magnitudes greater than the recommended limits. This finding indicates the reality that human sewage input could be the major source of the enteric pathogenic contamination of stormwater (Sidhu et al., 2013).

A final study variable for determining water quality characteristics is that of flow intensity in relation to bacterial and pathogenic contamination. Interestingly, several studies have produced contradictory conclusions in regards to this topic. First, Bougeard et al. concluded that most of the *E. coli* peaks occurred simultaneously with increases in river flow (Bougeard et al., 2011). In addition, McCarthy et al. also found that two sample sites revealed that *E. coli* densities were highly correlated with the average flow intensity (McCarthy, Mitchell, Deletic, & Diaper, 2007). On the contrary, Chase et al. concluded that greater concentrations of fecal coliforms and *E. coli* concentrations were observed under no-flow conditions, and specifically that a significant negative correlations was observed between the flow rate and the concentrations of fecal coliforms in the water column. Moreover, lower concentrations of these fecal indicators were found under flowing conditions when compared to nonflowing conditions (Chase et al., 2012). Finally, Surbeck et al. suggested that the concentrations of FIB and F+ coliphages exhibit little-to-no dependence on streamflow rates (Surbeck et al., 2006).

2.3 Fecal Indicator Bacteria and Virus in Sediment

The presence of FIB and viruses within sediment underlying surface waters is a frequently researched topic when considering the influencing factors of water quality. However, the research available provides differing results. Some researchers conclude a low presence of these microbial and pathogenic indicators in sediment and that further studies may not be beneficial, while other researchers found that a high concentration of microbial and pathogenic indicators found in the sediment could play a role in the contamination of the water column. For instance, Casteel et al. only found detectable levels of *E. coli* in 7% and 4% of samples and relatively low levels of coliphages taken at the same sediment sample site over time. As a result, the authors concluded that the low levels of fecal contamination found in the soil must suggest that these microbes are not suitable indicators for determining the presence of contamination in the soil (Casteel, Sobsey, & Mueller, 2006). Also, the research of Luther et al. on Hawaiian surface waters found that FRNA coliphages were below detectable levels (<3 per 10 grams of soil) in all soil samples (Luther & Fujioka, 2004). On the contrary, Pote et al. found that human fecal bacteria highly increased in the sediments that were contaminated with effluent from a wastewater treatment plant (WWTP). In fact, PCR analysis revealed that all sediment samples had positive findings of *E. coli,* while the accumulation of FIB in several depths of sediment cores indicates the presence of human pollution in the lake before and after the input of WWTP effluent (Pote et al., 2009). In addition, Ouattara et al. found the abundance of *E. coli* in the river sediments to be high, containing between 102 and 105 FIB per dry weight (Ouattara, Passerat, & Servais, 2011).

Some researchers not only reported the presence of contamination of sediment samples, but also suggested that the sediment may act as a reservoir for the microbial and pathogenic indicators, thereby further decreasing the quality of the water column. One study found that, although rainfall was negligible, the surface water was contaminated with higher than expected concentrations of FIB and concluded that a possible reservoir population may exist in the underlying sediment (Coulliette & Noble, 2008). Ibekwe et al., whose research sample site found nearly undetectable concentrations of FIB in the water column but substantial concentrations in the underlying sediment concluded that soils are effective filters for the transport of bacterial pathogens through the subsoil to the groundwater (Ibekwe et al., 2011). A study along a coastal surface water source suggested that sediments could serve as temporal sources of *E.* coli since the concentrations were found to be 63 times greater in the sand and sediment when compared to the lake water (Ishii et al., 2007). LaLiberte et al. conducted an interesting study which discovered that *E. coli* is able to survive and grow (up to 107 bacteria per gram) for several days in aquatic sediment. More importantly, these findings could indicate that the presence of FIB in surface water may not always be a result of recent fecal contamination of the surface water, but possibly a resuspension of previously sediment-bound bacteria (LaLiberte & Grimes, 1982). A similar study of Hawaii surface waters also found ambient concentrations of FIB to be consistently high in the soil, concluding that the soil was the source of FIB in the streams (Luther & Fujioka, 2004). Finally, Skraber et al. found that all 24 sediment sample sites were positive for F-specific phages although their concentrations in 46% of the overlying water column samples were undetectable. Moreover, the inactivation of these bacteriophages in both clay and sand sediments over a 1-month period was negligible, indicating that persistent deposits of viruses could lead to accumulation in underlying sediments (Skraber, Schijven, Italiaander, & de Roda Husman, 2009).

Not only is the presence or absence of fecal indicator contamination among sediment samples a necessary research topic, but also the impact that contaminated sediments may have on the quality of the overlying surface waters. Luther et al. concluded that the source of the fecal contamination in the Hawaiian streams was a result of the high ambient concentrations of FIB in the sediment (Luther & Fujioka, 2004). However, although Ouattara et al. discovered that the microbial load in sediments could sometimes be high, the contribution of resuspension events was only significant in two rivers. Based on their calculations, the researchers found that the potential resuspended *E. coli* represented only 1% of the contamination in the water column at 6 out of 12 sites and between 1 - 10% at 4 out of 12 sites, while only high contributions occurred at the remaining 2 sites (32% and 52%). Therefore, with the exception of 2 rivers, the FIB in sediments were not significant contributors to river water contamination during resuspension events (Ouattara et al., 2011).

2.4 MS2 as a Proxy for Detection Contamination of Enteric Viruses

Several studies have confirmed the fact that the bacteriophage MS2 could serve as an effective indicator for detecting the presence of contamination, specifically that of enteric viruses. F-specific RNA phages were found to survive in a disinfectant-free environment longer than norovirus, suggesting that they could become an indicator for enteric viruses (Allwood, Malik, Hedberg, & Goyal, 2003). Luther et al. discovered even more promising results, explaining that FRNA coliphages were still present in significant concentrations within treated sewage effluents although the FIB were drastically reduced, which is a characteristic similar to human enteric viruses. This indicates that monitoring sewage effluents for FIB alone may not adequately detect viral contamination (Luther & Fujioka, 2004). The researchers concluded the study explaining that these phages can be consistently isolated from WWTP wastewater, along with several other animal species, further verifying their ability to identify sources of fecal contamination within a watershed (Cole et al., 2003). Furthermore, it is known that FIB are not suitable indicators for enteric viruses since levels of virus tend to me lower than bacteria. Thus, DiDonato et al. conducted a study that found a correlation between all FIB and F+ coliphages (DiDonato et al., 2009). When considering the generalizability of MS2 as a proxy for enteric viruses, Lucena et al. found that the concentrations and trends of both FIB and bacteriophages were similar in the different geographical locations being studied. Not only did bacteriophages persist longer than fecal coliforms and enterococci, but they were also more highly correlated to FIB than when all parameters were considered together. More importantly, considering MS2 as an indicator for fecal contamination is an easy, fast, and inexpensive method highly suitable for developing countries (Lucena et al., 2003). Finally, F-specific coliphages are non-pathogenic, found in higher concentrations in the aqueous environment than human enteric viruses, and can be rapidly and easily cultivated for investigation (Skraber et al., 2009).

The fact that MS2 can be detected and detected within several different species allows a unique opportunity to identify point sources of fecal contamination within surface waters. First, these bacteriophages can be found in surface water samples and rainfall. Brion et al. found that F-specific coliphages were strongly associated with rainfall events (Brion et al., 2002). F+ coliphage recovery from surface waters, which was detected in 60% of the samples, was also found to be influenced by rainfall events with storm events increasing the frequency of phages from 50% at baseline to 88% following a storm event (Cole et al., 2003). Similar to that of FIB, the concentrations of f-specific RNA coliphages entering stormwater treatment systems appeared to reflect the intensity and frequency of rainfall, with detection only occurring during intense or prolonged rainfall (Davies et al., 2003).

MS2 has also been linked to municipal wastewater samples in high proportions (Cole et al., 2003). Griffith et al. confirmed that F+ coliphages were reliable in identifying sewage contamination, as well as excluding samples which did not contain human contamination (Griffith, Weisberg, & McGee, 2003). Furthermore, MS2 can persist in OWTS for several months. Although the levels were found to decline over time, the decline was not drastic and the presence of the bacteriophage was found in surface waters adjacent to the OWTS up to 25 days after contamination (Habteselassie et al., 2011).

Finally, MS2 could also reflect the impact of urbanization on the quality of surface waters. The isolation of F+ phage was found to be associated with urbanization and increased human activity, and can therefore detect sporadic and unexpected fecal contamination events based on changes in isolation frequency, quantity, and sero/genotype (Brion et al., 2002). Cole et al. also discovered that F+ coliphages were more frequently recovered from surface waters more frequently impacted by humans and animals (Cole et al., 2003). However, results from another study could not detect FNRA coliphages in any of the 20 human fecal samples, suggesting that, although they may be reliable markers for sewage contamination, they may not be indicative of direct contamination by feces (Luther & Fujioka, 2004).

2.5 Turbidity as a Proxy for Microbial and Pathogenic Contamination

Several research studies have indicated that levels of surface water turbidity often reflect the levels of microbial and pathogenic contamination within the water. Chase et al. observed significant positive correlations between *E. coli* and turbidity (Chase et al., 2012). Another study found similar results, and also discovered that peaks in pathogen numbers frequently preceded the peaks in number of FIB and turbidity, and at times prior to increases in turbidity from baseline (Dorner et al., 2007). After the occurrence of a waterborne outbreak related to Lake Erie, Fong et al. discovered the presence of a massive influx of turbidity surrounding the affected island. Moreover, three of the five cleanest sites experienced low turbidity, while the one of the most contaminated sites had high turbidity (Fong, Griffin, & Lipp, 2005). A recent study in Atlanta further confirmed the association between raw water turbidity and ensuing gastrointestinal (GI) illness. This study concluded that the association between raw water with high turbidity and GI illness were strongest in children aged five and younger who consumed the raw water six to nine days prior to the illness (Tinker et al., 2010).

Some authors have not only studied the association between surface water turbidity and contamination, but have also researched the pathways in which turbidity could be linked to contamination, primarily through rainfall. Astrom et al. discovered a positive correlation between turbidity and accumulated precipitation, suggesting a relationship between upstream precipitation, high turbidity and the microbial load. The authors further conclude that turbidity, as well as precipitation, should be promoted as complementary monitoring tools for surface water contamination (Astrom, Pettersson, & Stenstrom, 2007). Research conducted by Dorner et al. also found good correlations with turbidity during large wet weather events, and found that during these events, the density of total and fecal coliforms increased by more than 2 orders of magnitude with peaks measures coinciding with peaks in turbidity as well (Dorner et al., 2007).

2.6 Dissolved Oxygen as an Indicator for Microbial Load

Dissolved oxygen (DO) is a commonly studied characteristic of surface water quality studies; however, not all studies suggest the same conclusions in regards to the relationship between DO and microbial and pathogenic contamination. One study researching the survival of *E. coli* found that the reduction of *E. coli* was positively influenced by DO since positive increases in DO promoted the decay of *E. coli* (Cheng, Niu, & Kim, 2013). Another study of a highly polluted surface water source suggested a trend between an increase in total coliforms and a decrease in DO (Karn & Harada, 2001). However, Fong et al. concluded that the presence of fecal and total coliforms was positively related to DO (Fong et al., 2005).

Some researchers have sought to discover the pathway that could explain the role that DO plays on surface water contamination. Karn et al., who found that total coliforms increased as DO decreased, mentioned the fact that the surface water samples were taken from a river that was comprised of 85% municipal sewage (Karn & Harada, 2001). A study performed by Maane-Messai et al. discovered that within an area of twice as much pollutant load, the DO is relatively weak (55%). Furthermore, the downstream levels of dissolved oxygen were found to be close to zero, which was explained by the researchers to be due to the significant amount of urban effluent, input of industrialized wastes, and upstream contamination (Maane-Messai et al., 2010). Wu et al. determined that rivers in the vicinity of cities where discharge of industry and domestic wastewater possessed decreased DO levels due to the decomposition of organic compound. Moreover, rivers flowing through the countryside, where the pollutant load was much smaller, had considerable higher DO levels when compared to that of the rivers throughout the cities (Wu et al., 2011).

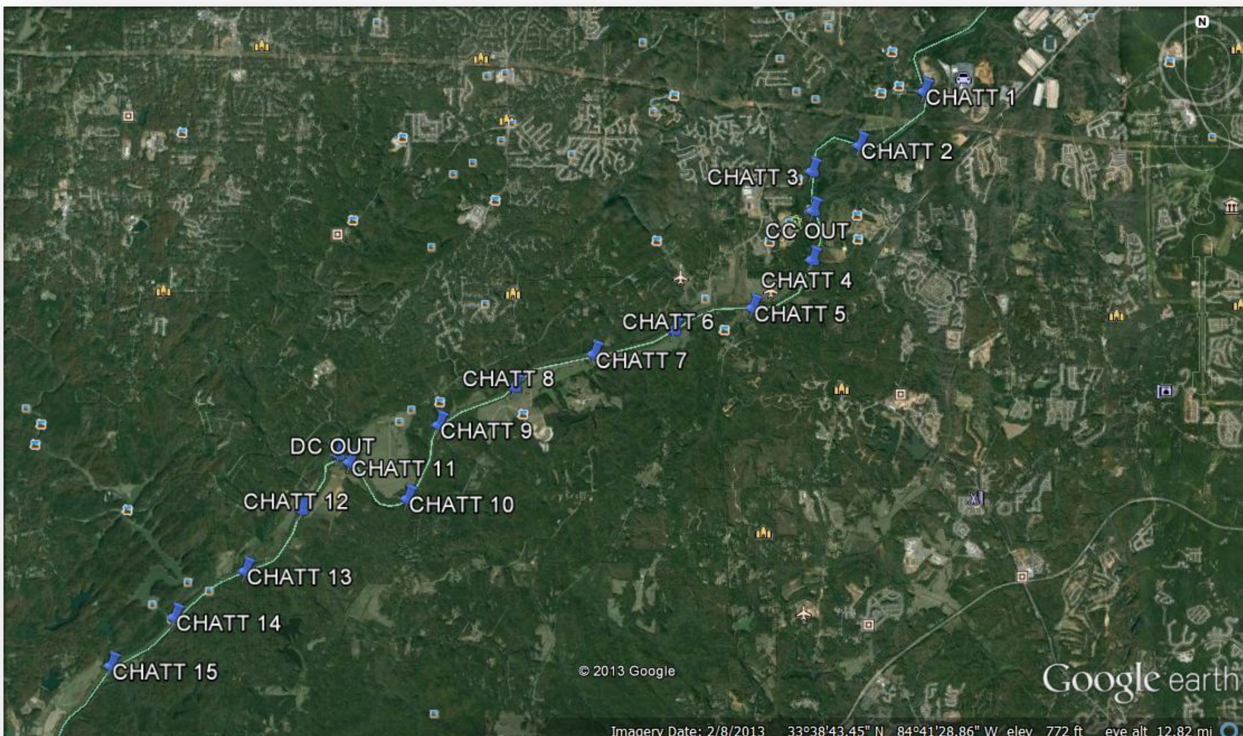
CHAPTER III

METHODS

3.1 River and Creek Sample Site Description

Samples were collected at fifteen sites along a fourteen mile stretch of the urbanized section of the Chattahoochee River, with each site located approximately one mile apart.

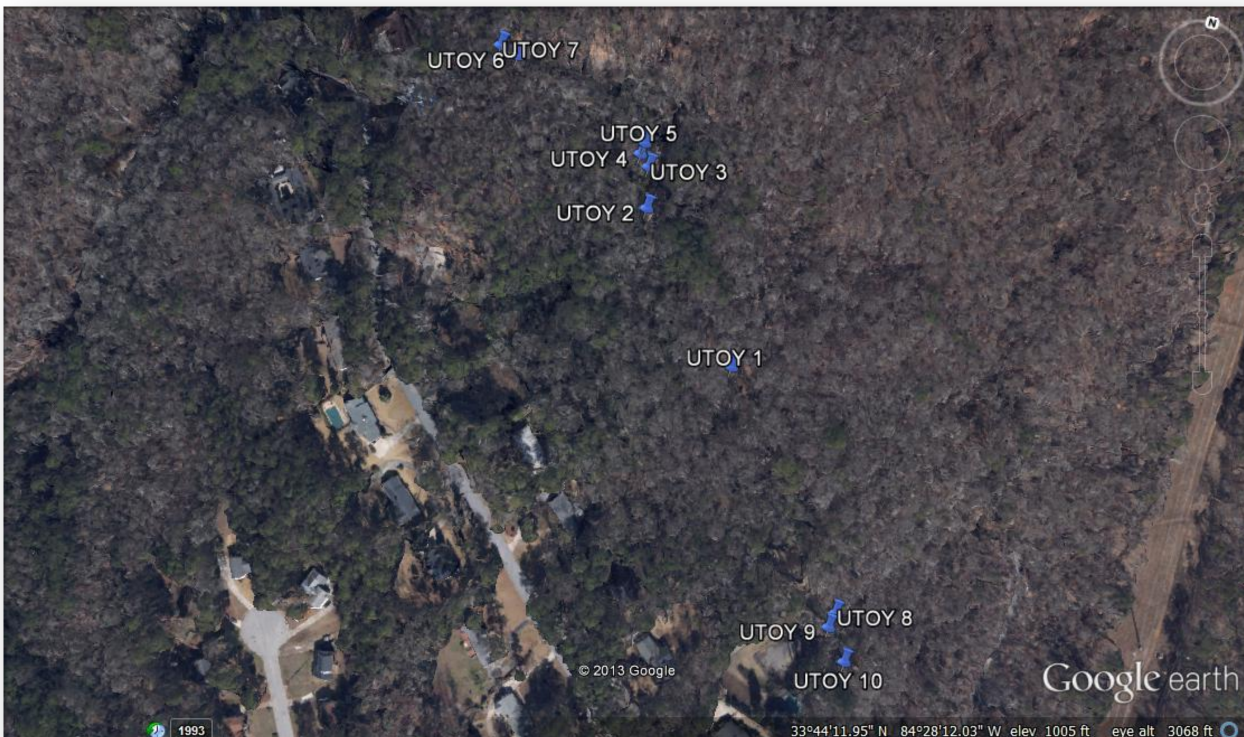
Map 1: Chattahoochee River Sample Sites



In addition, two wastewater treatment outfalls were sampled, the Camp Creek Outfall located between sites three and four and the Douglas County Outfall between sites eleven and twelve.

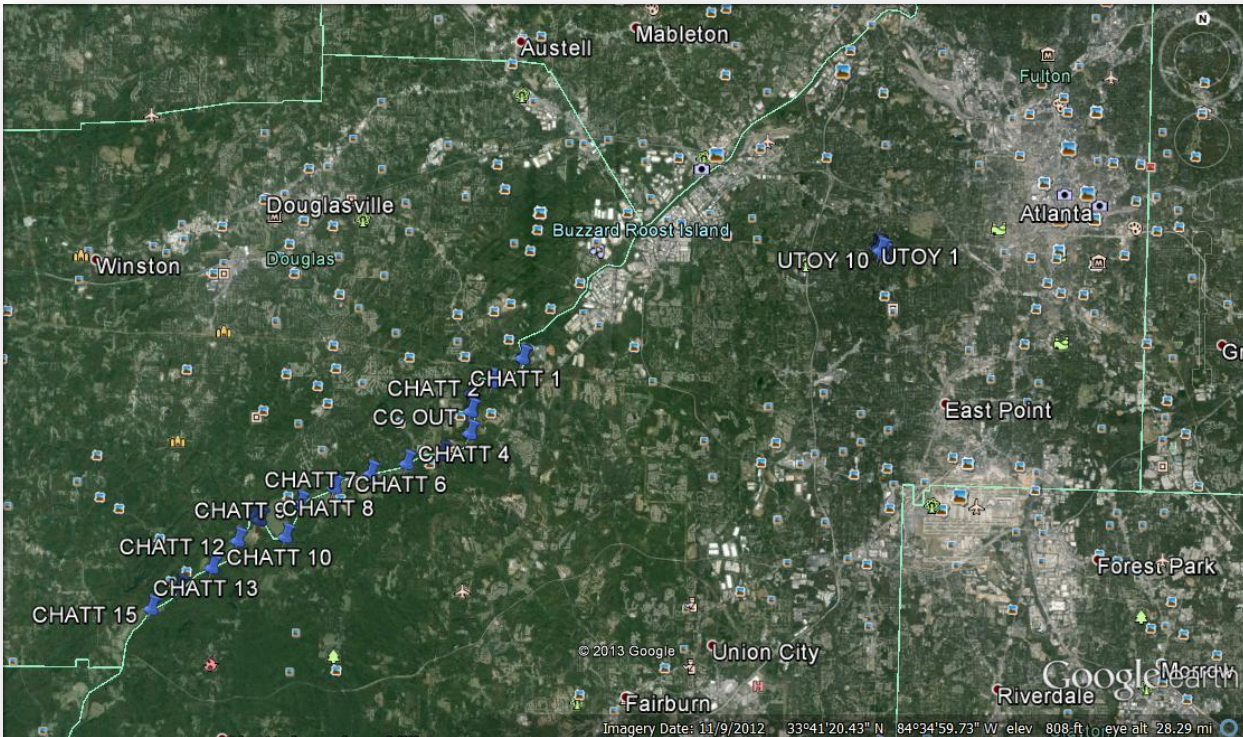
Utoy Creek, a thirty-four square mile watershed located approximately five miles above the mouth of the Chattahoochee River Basin, into which it flows, is surrounded by an area of land that is highly urbanized and residential. Ten sample sites, with distances varying between 23 feet and 0.1 miles, are located in the center of a residential neighborhood. The overall distance from the most upstream site to the most downstream site is 0.27 miles.

Map 2: Utoy Creek Sample Sites



The approximate distance from the last sample site of the Utoy Creek to the first sample site of the Chattahoochee River is 9.73 miles.

Map 3: Chattahoochee River and Utoy Creek Sample Sites



3.2 Sample Collection

3.2.1 Chattahoochee River

The Chattahoochee River was sampled on 4/17/13, 5/10/13, 7/29/13, 8/13/13, 9/5/13, 9/18/13, and 10/3/13. At each of the fifteen samples sites and at the two outfall sites, one liter of water was collected by grab sample method using sterilized bottles. In four of the sampling rounds, two samples were taken upstream and downstream of the Camp Creek Outfall to be sent to the University of Arizona to be analyzed for the presence the pepper mottle virus. Effluent from the Camp Creek Outfall was taken directly from the outfall pipeline. However, effluent from the Douglas County Outfall was taken within close proximity to the pipeline rather than directly from the source if the outfall could not be reached by boat. Time, date, geographic location (latitude and longitude), and dissolved oxygen (DO) were recorded at each of the sample sites on each day of sampling. Coolers filled with ice were used to preserve the samples during transport from the river to the Georgia State University (GSU) School of Public Health (SPH) lab. Samples remained on ice until they were processed, usually within one hour.

3.2.2 Utoy Creek

The Utoy Creek was sampled on 6/19/13, 6/26/13, 7/17/13, 7/24/13, 8/8/13, 8/21/13, and 9/11/13. At each of the ten sample sites, one liter of water and varying quantities sediment samples (ranging from 26.77 grams to 208.6 grams) were collected. Water samples were collected by grab sample method using sterilized bottles and sediment samples were collected using a sediment corer instrument and placed into sterilized bottles. Time, date, and geographic location (latitude and longitude) were recorded for each sample site at each day of sampling. Coolers filled with ice were used to preserve the samples during transport from the creek to the GSU SPH lab. Samples remained on ice until they were processed, usually within one hour.

3.3 Detection of *Escherichia coli* by membrane filtration

3.3.1 Water Samples

Materials included the following items: sidearm flasks, magnetic filter funnels, 0.45 micron filters, 100% ethanol, 60x15mm plates containing BioRad Rapid *E. coli* 2 agar (thawed and not older than 2 weeks), forceps, bunson burner, and an incubator set to 35^{o}C.

Methods were as follows: negative controls were collected prior to filtration of each sample. Forceps were placed in 100% ethanol and sterilized in a flame before placing the filter on the magnetic filter funnel. The funnel was rinsed with deionized (DI) water before placing the filter on a plate. These steps were repeated for all samples, where each sample site had its own filter funnel, negative control, two dilutions at 10mL and two dilutions at 50mL. Each filter was rinsed with DI water after each dilution had been filtered to ensure that the entire sample was filtered. Note: each negative control and dilution had its own filter and plate. Once each sample was filtered, the plates were placed in an incubator at 35^{o}C for 18-24 hours. After incubation, plates were placed on a light box to count colonies. Colony counts were expressed as CFU/100mL.

3.3.2 Sediment Samples

Procedures for sediment samples were the same as that for the water samples with two additional steps prior to the above methods: PBS was added to each sample, and each sample was placed on a shaker for 15 minutes prior to membrane filtration to elute bacteria from soil particles. Also, 1ml dilutions were filtered instead of 10ml, and only one dilution of 10mL was filtered rather than two dilutions of 50mL (ex: each sample included a negative control, two 1mL dilutions, and one 10mL dilution).

3.4. Detection of MS2 by Spot Plate Enrichment Assay

Water samples were processed according to the EPA's Method 1601: Male-specific (F+) and Somatic Coliphage in Water by Two-step Enrichment Procedure (EPA, 2001).

3.5 Data Sources

Riverflow data obtained from the USGS website (USGS site 02336490 Chattahoochee River at GA 280). (USGS, 2013) Rainfall data was obtained from georgiaweather.net based on the Atlanta sample site (Note: data was not available from the USGS website for our sampling site). (Georgia Automated Environmental Monitoring Network, 2013)

DO was determined at each Chattahoochee sample site by a trained staff member of the CRK. Using a Hach turbidimeter, turbidity was determined in the GSU SPH lab while the samples were being processed.

3.7 Statistical Analyses

All original data was organized and stored in Microsoft Excel 2010. Prior to statistical analyses, Microsoft Excel 2010 was also used to convert all *E. coli* data into CFU/100ml and CFU/gr and a logarithmic transformation was used to ensure normality of the data. Graphs were created using GraphPad Prism version 5. Geographical data and images were stored and organized in Garmin BaseCamp version 4.2.5.0.

SPSS version 20 was used to perform statistical analyses of the data. The Shapiro-Wilk test for normality was used to determine that all data was normally distributed. Two-sample t-tests were used to determine the presence of spatial and temporal variations of *E. coli* and MS2 concentrations along the Chattahoochee River and Utoy Creek sample sites. The correlation between *E. coli* and MS2 between DO, turbidity, rainfall, and riverflow was determined using Spearman's rank correlation coefficient. Spearman's rank correlation coefficient was also used to determine the correlation between *E. coli* and MS2 at each sample site, as well as to determine the correlation between *E. coli* in the water and sediment samples from the Utoy Creek. To determine the impact of the discharge of effluent on the concentrations of *E. coli* and MS2 downstream of the two outfalls, paired-sample t-tests were conducted based on upstream and downstream sample sites (comparisons were calculated based on one site upstream and downstream, two sites upstream and downstream, and three sites upstream and downstream). For all statistical analyses, the level of significance was reported as $p < .05$.

CHAPTER IV

RESULTS

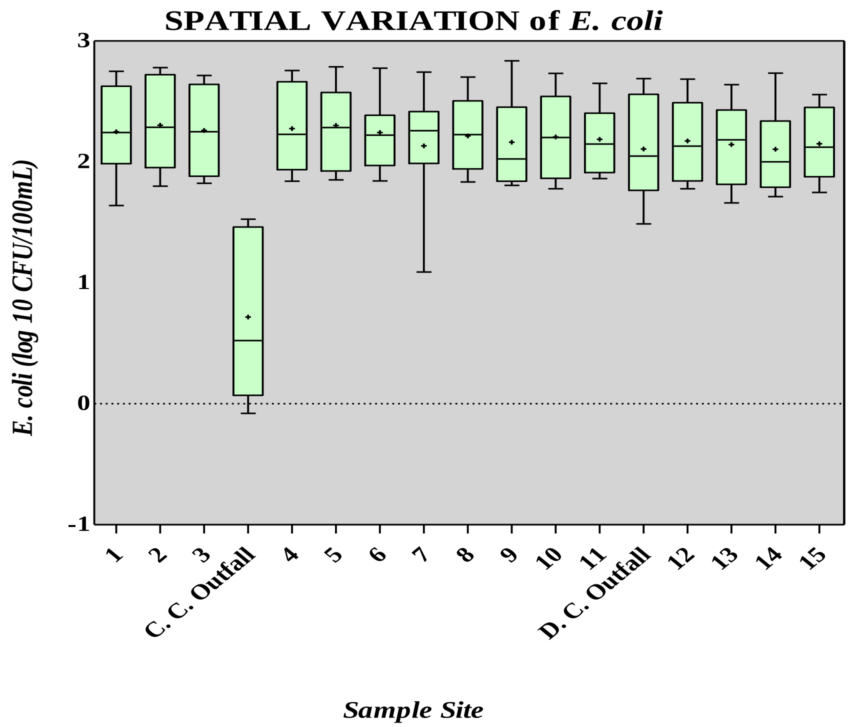
4.1 Chattahoochee River (Refer to Maps 1 and 3 in the Methods section)

Table 1: Univariate analyses of selected water quality variables sampled from the Chattahoochee River by site, Atlanta, Georgia, 2013.

	Range	Minimum	Maximum	Mean
E. coli* by site				
Site 1	1.11	1.64	2.75	2.25
Site 2	0.98	1.80	2.78	2.30
Site 3	0.89	1.82	2.72	2.26
Camp Creek Outfall	1.61	-0.08	1.53	0.72
Site 4	0.92	1.84	2.76	2.28
Site 5	0.94	1.85	2.79	2.30
Site 6	0.93	1.84	2.78	2.24
Site 7	1.65	1.09	2.74	2.13
Site 8	0.87	1.83	2.70	2.21
Site 9	1.03	1.81	2.84	2.16
Site 10	0.95	1.78	2.73	2.21
Site 11	0.79	1.86	2.65	2.19
Douglas County Outfall	1.20	1.48	2.69	2.11
Site 12	0.91	1.78	2.68	2.17
Site 13	0.98	1.66	2.64	2.14
Site 14	1.02	1.71	2.74	2.11
Site 15	0.81	1.75	2.56	2.15
Dissolved Oxygen by site**				
Site 1	2.10	6.60	8.70	8.10
Site 2	2.10	6.50	8.60	7.90
Site 3	2.00	6.50	8.50	7.97
Site 4	1.90	6.60	8.50	7.98
Site 5	1.80	6.60	8.40	7.90
Site 6	1.76	6.60	8.36	7.88
Site 7	1.70	6.70	8.40	7.91
Site 8	1.74	6.60	8.34	7.92
Site 9	1.72	6.60	8.32	7.85
Site 10	1.78	6.50	8.28	7.81
Site 11	1.88	6.40	8.28	7.60
Site 12	2.10	6.20	8.30	7.74
Site 13	2.00	6.20	8.20	7.73
Site 14	2.00	6.20	8.20	7.64
Site 15	2.00	6.30	8.30	7.72
Turbidity by site***				
Site 1	18.23	2.17	20.40	9.64
Site 2	56.50	2.10	58.60	22.05
Site 3	29.50	2.20	31.70	13.92
Camp Creek Outfall	1.32	0.19	1.50	0.87
Site 4	27.08	2.22	29.30	13.22
Site 5	22.85	2.45	25.30	12.91
Site 6	32.86	2.34	35.20	17.90
Site 7	27.27	2.23	29.50	14.78
Site 8	44.76	2.44	47.20	14.98
Site 9	39.75	2.55	42.30	15.63
Site 10	30.67	2.43	33.10	11.57
Site 11	29.76	2.64	32.40	13.57
Douglas County Outfall	28.07	2.83	30.90	11.94
Site 12	29.70	2.60	32.30	13.35
Site 13	31.25	2.75	34.00	16.19
Site 14	31.68	2.82	34.50	11.23
Site 15	31.73	2.97	34.70	12.38

* All *E. coli* concentrations are presented as log 10 CFU/100mL
**DO values are presented as mg/L
***Turbidity values are presented as NTU

Figure 1: Spatial Variation of *E. coli* among Chattahoochee Water Samples



As shown in Table 1 and Figure 1, the mean *E. coli* concentrations across sites for all sampling dates were similar, mean E. coli levels were approximately 2 $\log_{10}$ CFU/100 mL across sites. There were no statistically significant differences in mean *E. coli* concentrations between sample sites (p = .244 between sites 14 and 2, and p = .185 between sites 14 and 5; Table 3a).

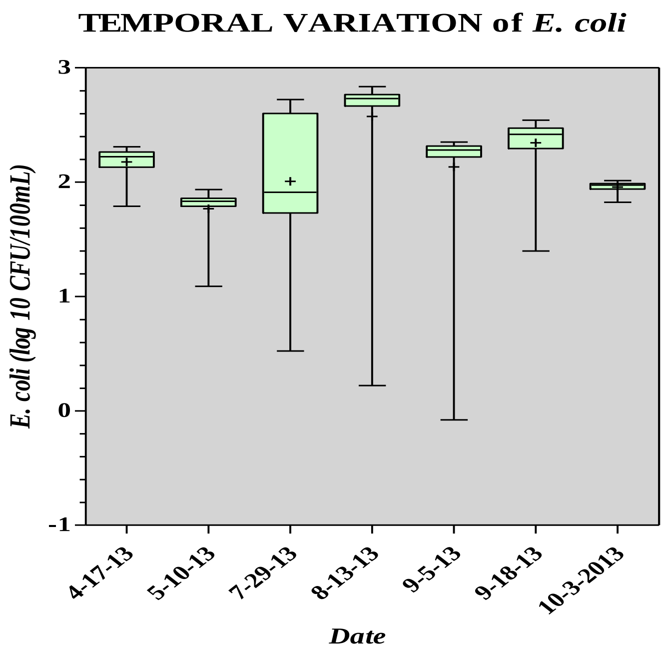
Table 3a: Determination of statistical significance between samples with the highest and lowest mean values of *E. coli* among water samples from the Chattahoochee River, Atlanta, Georgia, 2013.

	Mean Values		95% Confidence Interval of the Mean Difference	P-value*
	Lowest	Highest		
Mean concentrations of *E. coli***				
Between site 14 (lowest) and site 2 (highest)	2.11	2.30	-.1178 - .5758	.244
Between site 14 (lowest) and site 5 (highest)	2.11	2.30	-.1241 - .5156	.185
Between sample dates 5/10/13 (lowest) and 8/13/13 (highest)	1.77	2.57	-1.105 - -.5053	< .0001

* Pearson's correlation coefficient with level of significance reported as p < .05

** *E. coli* concentrations in 10 log CFU/100mL

Figure 2: Temporal variation of *E. coli* among Chattahoochee Water Samples



3a).

Table 2: Univariate analyses of selected water quality variables sampled from the Chattahoochee River by date, Atlanta, Georgia, 2013.

	Range	Minimum	Maximum	Mean
E. coli* by date				
4/17/2013	0.52	1.79	2.31	2.18
5/10/2013	0.85	1.09	1.94	1.77
7/29/2013	2.20	0.52	2.72	2.00
8/13/2013	2.61	0.22	2.84	2.57
9/5/2013	2.43	-0.08	2.35	2.13
9/18/2013	1.14	1.40	2.54	2.34
10/3/2013	0.19	1.82	2.01	1.96
Dissolved Oxygen by date**				
4/17/2013	0.41	8.09	8.50	8.31
5/10/2013				
7/29/2013	0.40	7.40	7.80	7.60
8/13/2013	0.50	6.20	6.70	6.47
9/5/2013	0.60	8.10	8.70	8.33
9/18/2013	0.90	7.80	8.70	8.21
10/3/2013	1.40	7.10	8.50	8.17
Turbidity by date***				
4/17/2013				
5/10/2013				
7/29/2013	38.29	1.21	39.50	19.77
8/13/2013	58.00	0.60	58.60	30.03
9/5/2013	30.72	0.19	30.90	10.42
9/18/2013	6.31	1.50	7.81	4.66
10/3/2013	0.87	2.10	2.97	2.48

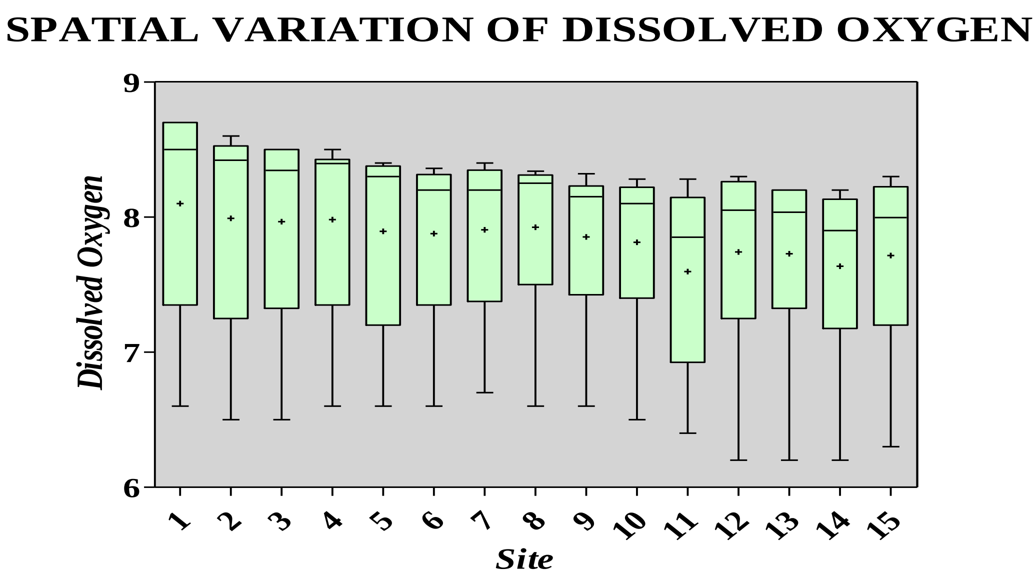
* All *E. coli* concentrations are presented as log 10 CFU/100mL

**DO values are presented as mg/L

*** Turbidity values are presented as NTU

As shown in Table 2 and Figure 2, there is a variation found among *E. coli* concentrations across sample dates for all sample sites, with the lowest mean *E. coli* concentration found on 5/10/13 (1.77 $\log_{10}$ CFU/100mL) and the highest mean *E. coli* concentration found on 8/13/13 (2.57 $\log_{10}$ CFU/100mL). Paired samples t-test determined that the differences in mean *E. coli* concentrations between these two sample dates were statistically significant ($p < .0001$; Table 3a).

Figure 3: Spatial Variation of Dissolved Oxygen among Chattahoochee Water Samples



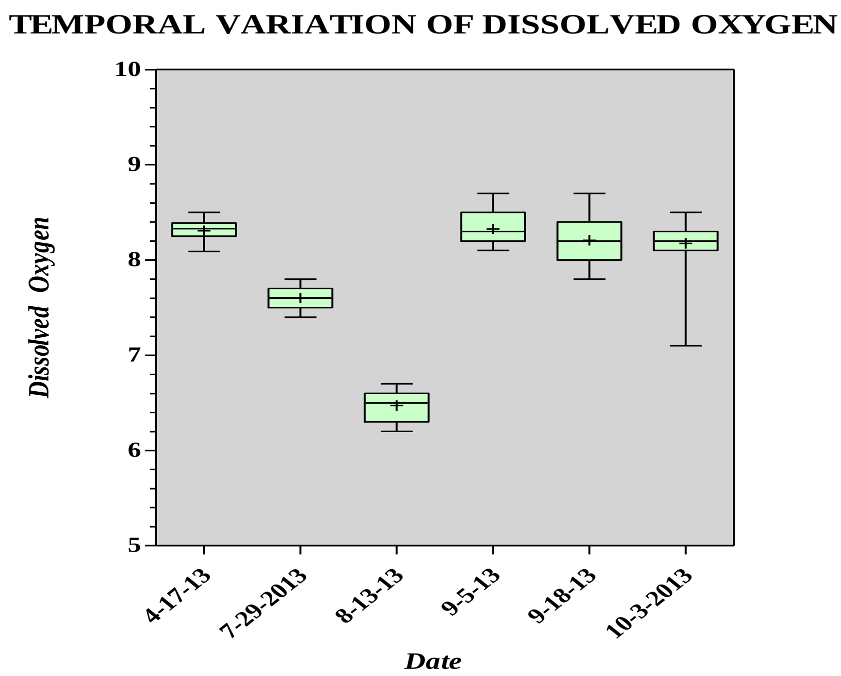
As shown in Table 1 and Figure 3, the mean DO values across sites for all sampling dates were similar. There were no statistically significant differences in mean DO values between sample sites (p = .101; Table 3b).

Table 3b: Determination of statistical significance between samples with the highest and lowest mean values of DO among water samples from the Chattahoochee River, Atlanta, Georgia, 2013.

	Mean Values		95% Confidence Interval of the Mean Difference	P-value*
	Lowest	Highest		
Mean values for DO**				
Between sites 11 (lowest) and 1 (highest)	7.60	8.10	-.1078 - .8778	.101
Between sample dates 8/13/13 (lowest) and 9/5/13 (highest)	6.47	8.33	-1.956 - -1.751	< .0001

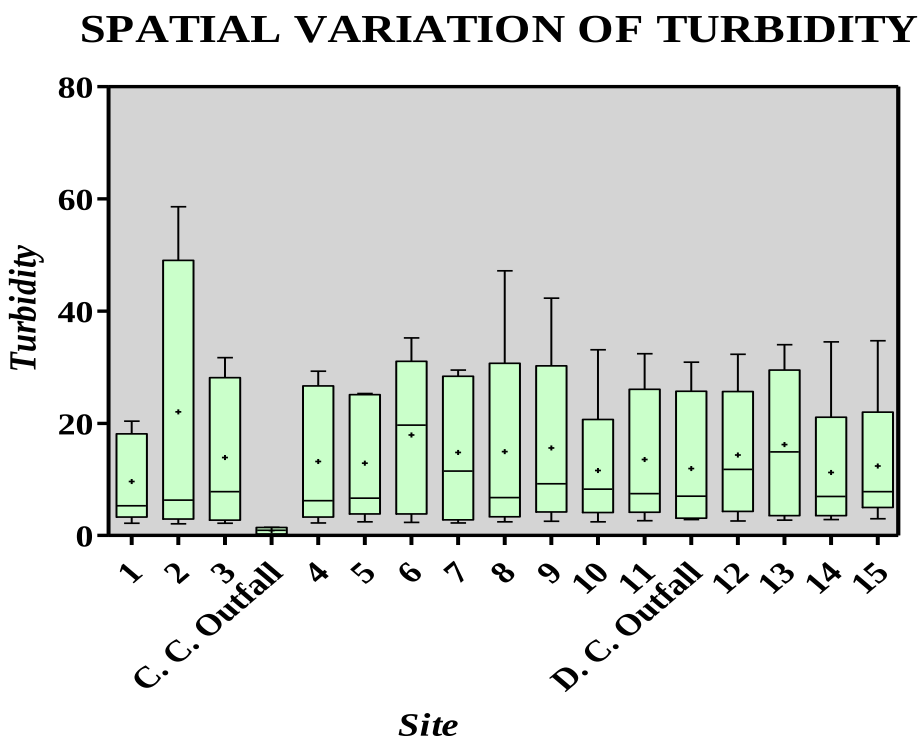
* Pearson's correlation coefficient with level of significance reported as p < .05
** DO values in mg/L

Figure 4: Temporal Variation of Dissolved Oxygen among Chattahoochee Water Samples



As shown in Table 2 and Figure 4, there is a variation found among DO values across sample dates for all sample sites, with the lowest mean DO value found on 8/13/13 (6.47 mg/L) and the highest mean DO value found on 9/5/13 (8.33 mg/L). Paired samples t-test determined that the differences in mean DO values between these two sample dates were statistically significant ($p < .0001$; Table 3b).

Figure 5: Spatial Variation of Turbidity among Chattahoochee Water Samples



As shown in Table 1 and Figure 5, the mean turbidity values across sites for all sampling dates were similar. Further analysis revealed that there were no statistical significant differences in mean turbidity values between sample sites (p = .191; Table 3c).

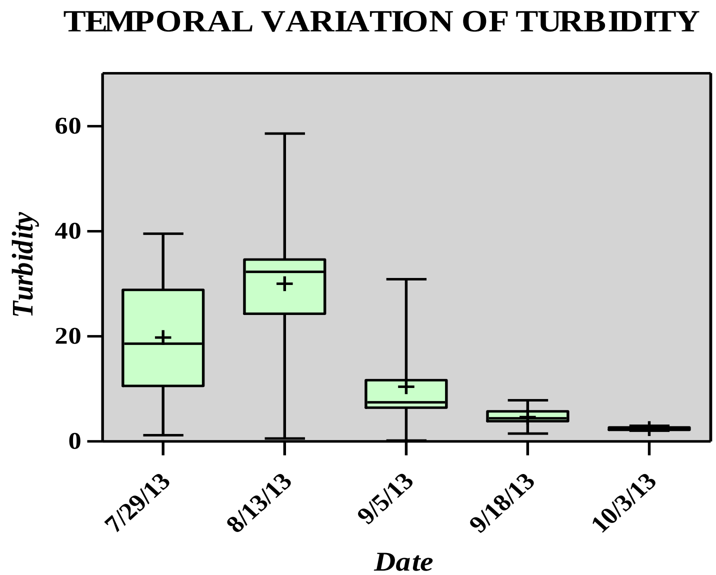
Table 3c: Determination of statistical significance between samples with the highest and lowest mean values of turbidity among water samples from the Chattahoochee River, Atlanta, Georgia, 2013.

	Mean Values		95% Confidence Interval of the Mean Difference	P-value*
	Lowest	Highest		
Mean values for Turbidity**				
Between sites 1 (lowest) and 2 (highest)	9.64	22.05	-34.34 - 9.518	.191
Between sample dates 10/3/13 (lowest) and 8/13/13 (highest)	2.48	31.87	35.36 - -23.41	< .0001

* Pearson's correlation coefficient with level of significance reported as p < .05

** Turbidity values in NTU

Figure 6: Temporal Variation of Turbidity among Chattahoochee Water Samples



As shown in Table 2 and Figure 6, there is a variation found among turbidity values across sample dates for all sample sites, with the lowest mean turbidity value found on 10/3/13 (2.48 NTU) and the highest mean turbidity value found on 8/13/13 (31.87 NTU). Paired samples t-test determined that the differences between the mean turbidity values between these two sample dates were statistically significant ($p < .0001$; Table 3c).

Table 4a: Analysis of Pearson's correlations between *E. coli* and Dissolved Oxygen sampled from the Chattahoochee River, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
***E. coli* and DO**		
Site 1	-0.875	.022
Site 2	-0.834	.039
Site 3	-0.752	.085
Site 4	-0.825	.043
Site 5	-0.809	.051
Site 6	-0.866	.026
Site 7	-0.643	.168
Site 8	-0.577	.231
Site 9	-0.687	.132
Site 10	-0.522	.288
Site 11	-0.280	.59
Site 12	-0.513	.298
Site 13	-0.507	.304
Site 14	-0.600	.208
Site 15	-0.366	.476

* Pearson's correlation coefficient with level of significance reported as $p < .05$

As shown in Table 4a, *E. coli* concentrations from the Chattahoochee water samples were found to be negatively correlated with DO at sites 1, 2, 4, and 6 ($p < .05$).

Table 4b: Analysis of Pearson's correlations between *E. coli* and Turbidity sampled from the Chattahoochee River, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
***E. coli* and Turbidity**		
Site 1	0.968	.007
Site 2	0.913	.03
Site 3	0.868	.056
Camp Creek Outfall	0.922	.078
Site 4	0.914	.03
Site 5	0.854	.065
Site 6	0.498	.393
Site 7	0.457	.439
Site 8	0.611	.274
Site 9	0.646	.239
Site 10	0.676	.21
Site 11	0.432	.468
Douglas County Outfall	-0.232	.768
Site 12	0.368	.543
Site 13	0.475	.418
Site 14	0.705	.184
Site 15	0.555	.331

* Pearson's correlation coefficient with level of significance reported as $p < .05$

According to Table 4b, *E. coli* concentrations from water samples were also found to be positively correlated with turbidity at sites 1, 2, and 4 ($p < .05$).

Table 4c: Analysis of Pearson's correlations between *E. coli* and Rainfall sampled from the Chattahoochee River, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
***E.coli* and Rainfall (Day Before)**		
Site 1	0.591	.163
Site 2	0.583	.169
Site 3	0.594	.159
Camp Creek Outfall	-0.389	.171
Site 4	0.624	.134
Site 5	0.641	.121
Site 6	0.779	.039
Site 7	0.520	.232
Site 8	0.677	.095
Site 9	0.788	.035
Site 10	0.659	.107
Site 11	0.698	.081
Douglas County Outfall	0.648	.164
Site 12	0.675	.096
Site 13	0.628	.131
Site 14	0.739	.058
Site 15	0.582	.171

* Pearson's correlation coefficient with level of significance reported as $p < .05$

As shown in Table 4c, *E. coli* concentrations from water samples was also positively correlated with rainfall the day before sampling at sites 6 and 9 ($p < .05$). However, Tables 4d and 4e reveal that no significant correlations among Chattahoochee water samples were found between *E. coli* concentrations and riverflow, or between *E. coli* concentrations and MS2.

Table 4d: Analysis of Pearson's correlations between *E. coli* and Riverflow sampled from the Chattahoochee River, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
***E. coli* and Riverflow**		
Site 1	-0.575	.177
Site 2	-0.498	.256
Site 3	-0.366	.42
Camp Creek Outfall	0.307	.615
Site 4	-0.367	.419
Site 5	-0.389	.388
Site 6	-0.306	.504
Site 7	-0.534	.217
Site 8	-0.039	.934
Site 9	0.065	.89
Site 10	-0.031	.947
Site 11	0.056	.904
Douglas County Outfall	0.185	.726
Site 12	0.078	.868
Site 13	0.122	.794
Site 14	0.232	.617
Site 15	0.183	.694

* Pearson's correlation coefficient with level of significance reported as p < .05

Table 4e: Analysis of Pearson's correlations between *E. coli* and MS2 sampled from the Chattahoochee River, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
***E.coli* and MS2**		
Site 1		
Site 2		
Site 3	-0.451	.31
Camp Creek Outfall	-0.632	.368
Site 4	-0.062	.894
Site 5	-0.110	.814
Site 6	-0.201	.666
Site 7	0.243	.599
Site 8	0.151	.746
Site 9	0.123	.793
Site 10	0.215	.643
Site 11	-0.031	.948
Douglas County Outfall	0.264	.668
Site 12	-0.055	.907
Site 13	0.442	.321
Site 14	0.421	.347
Site 15	0.546	.204

* Pearson's correlation coefficient with level of significance reported as p < .05

Table 5: Analysis of Pearson's correlations between MS2 and selected water quality variables sampled from the Chattahoochee River, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
MS2 and DO**		
Site 1		
Site 2		
Site 3	0.425	.401
Site 4	0.272	.602
Site 5	0.156	.768
Site 6	0.882	.02
Site 7	0.221	.674
Site 8	0.554	.254
Site 9	0.528	.282
Site 10	0.820	.046
Site 11	0.364	.502
Site 12	0.446	.375
Site 13	0.321	.535
Site 14	0.379	.459
Site 15	0.398	.434
MS2 and Turbidity		
Site 1		
Site 2		
Site 3	-0.607	.278
Camp Creek Outfall		
Site 4	-0.395	.51
Site 5	-0.193	.765
Site 6	-0.858	.063
Site 7	-0.492	.4
Site 8	-0.773	.125
Site 9	-0.834	.079
Site 10	-0.677	.209
Site 11	-0.696	.192
Douglas County Outfall	-0.990	.088
Site 12	-0.553	.334
Site 13	-0.105	.876
Site 14	-0.392	.515
Site 15	-0.355	.557

* Pearson's correlation coefficient with level of significance reported as $p < .05$

** Missing correlations are due to MS2 being counted as a constant during statistical analyses

Table 5 Continued: Analysis of Pearson's correlations between MS2 and selected water quality variables sampled from the Chattahoochee River, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
MS2 and Rainfall (Day Before)**		
Site 1		
Site 2		
Site 3	-0.258	.576
Camp Creek Outfall	0.333	.667
Site 4	-0.167	.721
Site 5	-0.354	.437
Site 6	-0.471	.286
Site 7	-0.167	.721
Site 8	-0.354	.437
Site 9	-0.354	.437
Site 10	-0.471	.286
Site 11	-0.354	.437
Douglas County Outfall	-0.408	.495
Site 12	-0.258	.576
Site 13	-0.258	.576
Site 14	-0.258	.576
Site 15	-0.258	.576
MS2 and Riverflow		
Site 1		
Site 2		
Site 3	0.048	.919
Camp Creek Outfall	-0.879	.121
Site 4	0.006	.989
Site 5	-0.316	.49
Site 6	-0.193	.678
Site 7	0.006	.989
Site 8	0.048	.918
Site 9	0.048	.918
Site 10	-0.193	.678
Site 11	-0.450	.311
Douglas County Outfall	-0.273	.657
Site 12	0.048	.919
Site 13	0.286	.534
Site 14	0.286	.534
Site 15	0.286	.534

* Pearson's correlation coefficient with level of significance reported as $p < .05$
** Missing correlations are due to MS2 being counted as a constant during statistical analyses

Based on data from Table 5, the presence of MS2 among Chattahoochee water samples was found to be positively correlated with DO at sites 6 and 10 ($p < .05$).

Table 6: Determination of spatial and temporal variation of mean *E. coli* concentrations based on the presence or absence of MS2 among water samples from the Chattahoochee River, Atlanta, Georgia, 2013.

	Mean Values		95% Confidence Interval of the Difference	P-value*
	MS2 Present	MS2 Absent		
Mean *E. coli* concentrations by site**				
Site 1				
Site 2				
Site 3	2.35	2.04	-.3986 - 1.024	.31
Camp Creek Outfall	1.53	0.71	-2.223 - 3.848	.368
Site 4	2.28	2.23	-9.750 - 1.087	.894
Site 5	2.33	2.26	-.6463 - .7844	.814
Site 6	2.31	2.19	-.5222 - .7485	.666
Site 7	2.08	2.42	-1.862 - 1.196	.599
Site 8	2.18	2.27	-.7653 - .5853	.746
Site 9	2.13	2.21	-.8896 - .7167	.793
Site 10	2.13	2.27	-.8809 - .5975	.643
Site 11	2.19	2.18	-.6123 - .6465	.948
Douglas County Outfall	2.01	2.24	-1.827 - 1.354	.668
Site 12	2.19	2.15	-.74661 - .8213	.907
Site 13	2.05	2.37	-1.051 - .4207	.321
Site 14	2.01	2.34	-1.127 - .4787	.347
Site 15	2.05	2.40	-.9509 - .2623	.204
Mean *E.coli* concentrations by date				
4/17/2013	2.17	2.19	-.2055 - .1723	.852
5/10/2013				
7/29/2013	2.06	1.55	-11.94 - 12.96	.705
8/13/2013	2.72	0.22	2.350 - 2.647	< .0001
9/5/2013	2.27	2.29	-.0779 - .0354	.433
9/18/2013	2.36	2.34	-.2880 - .3211	.909
10/3/2013	1.96	1.96	-.0608 - .0605	.996

* Pearson's correlation coefficient with level of significance reported as $p < .05$

** Missing correlations are due to MS2 being counted as a constant during statistical analyses

As shown in Table 6, mean concentrations of *E. coli* were similar for sites across all sample dates, regardless of the presence or absence of MS2 ($p > .05$). Also shown in Table 6, statistically significant differences in mean *E. coli* concentrations in the presence or absence of MS2 of all sample sites were found for sample date 8/13/13 ($p < .0001$).

Table 7: Determination of spatial variation of mean *E. coli* concentrations upstream and downstream the Camp Creek Outfall and Douglas County Outfall among water samples from the Chattahoochee River, Atlanta, Georgia, 2013.

	Mean Values		95% Confidence Interval of the Mean Difference	P-value*
	Upstream	Downstream		
Mean concentrations of *E. coli* at Camp Creek Outfall**				
Upstream/Downstream by 1 site	2.26	2.28	.0531 - .0205	.319
Upstream/Downstream by 2 sites	2.28	2.29	.0427 - .0297	.703
Upstream/Downstream by 3 sites	2.27	2.27	.0484 - .0444	.93
Mean concentrations of *E.coli* at Douglas County Outfall***				
Upstream/Downstream by 1 site	2.19	2.17	-.0560 - .0801	.68
Upstream/Downstream by 2 sites	2.20	2.16	-.0062 - .0803	.087
Upstream/Downstream by 3 sites	2.19	2.14	-.0071 - .0957	.087

* Pearson's correlation coefficient with level of significance reported as $p < .05$
** Comparison of sites 3 and 4; sites 2/3 and 4/5; and sites 1/2/3 and 4/5/6
***Comparison of sites 11 and 12; 10/11 and 12/13; and sites 9/10/11 and 12/13/14

As shown in Table 7, mean concentrations of *E. coli* were similar for sites upstream and downstream from both the Camp Creek Outfall and Douglas County Outfall. No statistically significant differences in mean *E. coli* levels were found between the upstream and downstream sample sites of the outfall sites, whether by one, two, or three sites upstream or downstream ($p > .05$).

4.2 Utoy Creek (Refer to Maps 2 and 3 in the Methods section)

Table 8: Univariate analyses of selected water quality variables sampled from the Utoy Creek by site, Atlanta, Georgia, 2013.

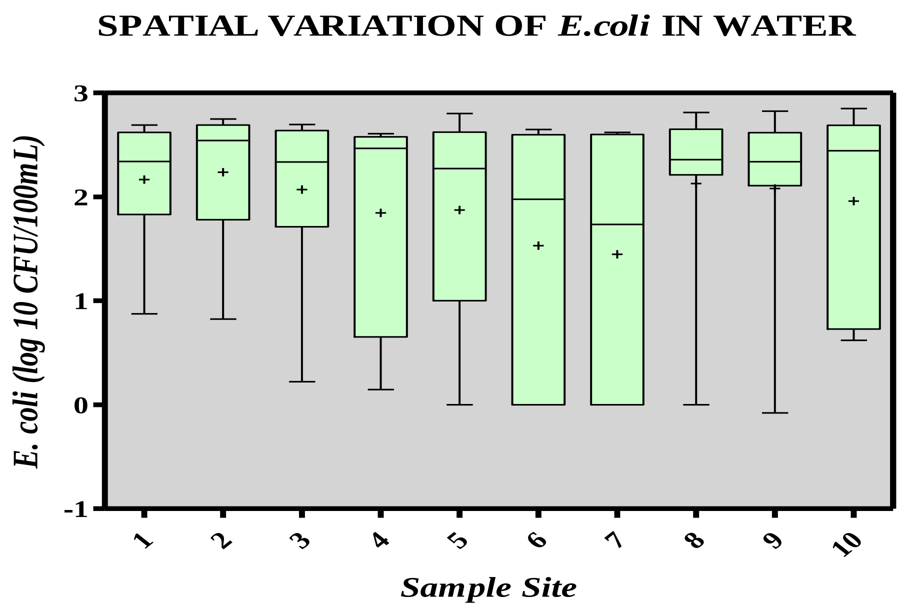
	Range	Minimum	Maximum	Mean
E. coli* in water by site				
Site 1	1.82	0.88	2.69	2.17
Site 2	1.93	0.82	2.75	2.24
Site 3	2.47	0.22	2.70	2.07
Site 4	2.46	0.15	2.61	1.85
Site 5	2.80	0.00	2.80	1.88
Site 6	2.65	0.00	2.65	1.53
Site 7	2.59	0.00	2.59	0.65
Site 8**	2.81	0.00	2.81	2.13
Site 9	2.90	-0.08	2.83	2.08
Site 10	2.23	0.62	2.85	1.96
***E.coli* in sediment by site**				
Site 1	1.99	-1.45	0.54	-0.39
Site 2	2.28	-1.79	0.49	-0.25
Site 3	2.82	-2.19	0.64	-0.29
Site 4	2.07	-1.67	0.4	-0.14
Site 5	2.77	-2.19	0.58	-0.34
Site 6	0.35	-0.03	0.33	0.14
Site 7	0.65	0.00	0.65	0.32
Site 8	1.67	-0.98	0.69	0.13
Site 9	2.77	-2.00	0.77	0.09
Site 10	1.46	-1.01	0.45	-0.03
Turbidity by site * **				
Site 1	5.99	2.27	8.26	5.23
Site 2	5.26	1.98	7.24	4.61
Site 3	5.07	2.20	7.27	4.74
Site 4	5.16	2.11	7.27	4.69
Site 5	4.55	2.75	7.30	5.03
Site 6	5.20	2.40	7.60	5.00
Site 7	5.91	2.06	7.97	5.02
Site 8	4.81	2.16	6.97	4.66
Site 9	4.00	2.43	6.43	4.57
Site 10	4.25	2.05	6.30	4.39

* All *E. coli* concentrations in water are presented as log 10 CFU/100mL and log 10 CFU/gr in sediment

**Sites 8-10 are upstream of site 1; the sites in order from upstream to downstream are as follows: 8, 9, 10, 1, 2, 3, 4, 5, 6, 7

*** Turbidity values are presented as NTU

Figure 7: Spatial Variation of *E. coli* among the Utoy Creek Water Samples



As shown in Table 8 and Figure 7, there is a variation found among *E. coli* concentrations in water across sample sites for all sample dates, with the lowest mean *E. coli* concentration found at site 7 (0.65 $\log_{10}$ CFU/100mL) and the highest mean *E. coli* concentration found at site 2 (2.24 $\log_{10}$ CFU/100mL). Paired samples t-test determined that the mean differences in mean *E. coli* concentrations in water at these two sample sites were statistically significant (p = .037; Table 10a).

Table 10a: Determination of statistical significance between samples with the highest and lowest mean concentrations of *E. coli* among water samples from the Utoy Creek, Atlanta, Georgia, 2013.

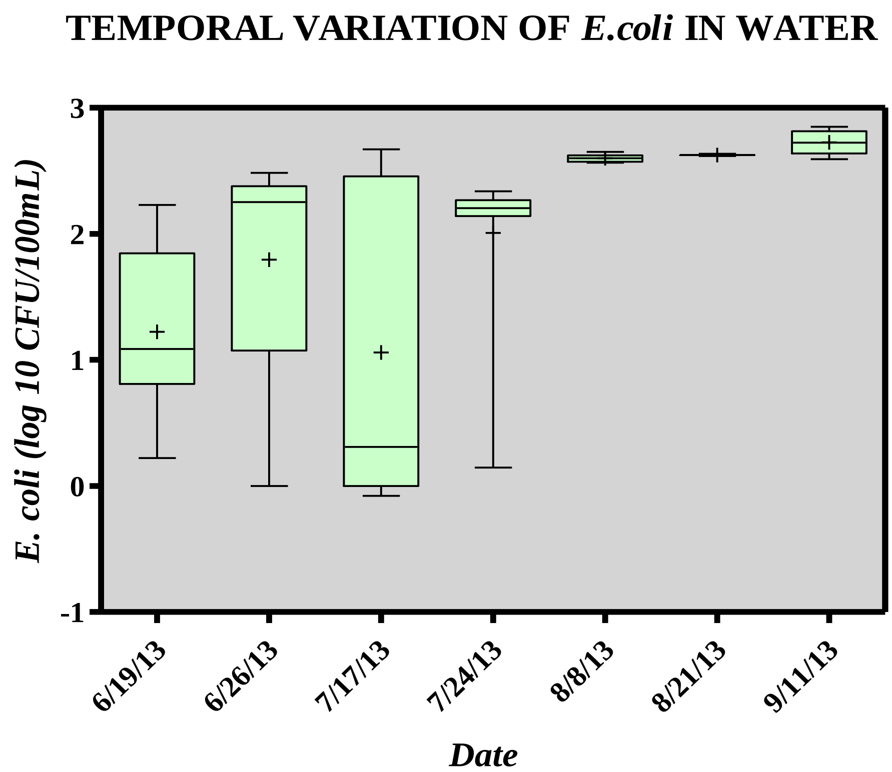
	Mean Values		95% Confidence Interval of the Mean Difference	P-value*
	Lowest	Highest		
Mean concentrations of *E. coli* in water**				
Between site 7 (lowest) and site 2 (highest)	0.65	2.24	.1364 - 3.041	.037
Between sample dates 7/17/13 (lowest) and 9/11/13 (highest)	1.06	2.73	-2.599 - -.7357	.003

* Pearson's correlation coefficient with level of significance reported as p < .05

** *E. coli* concentrations in log 10 CFU/100mL for water or log 10 CFU/gr for sediment

*** Turbidity values in NTU

Figure 8: Temporal Variation of *E. coli* among Utoy Creek Water Samples



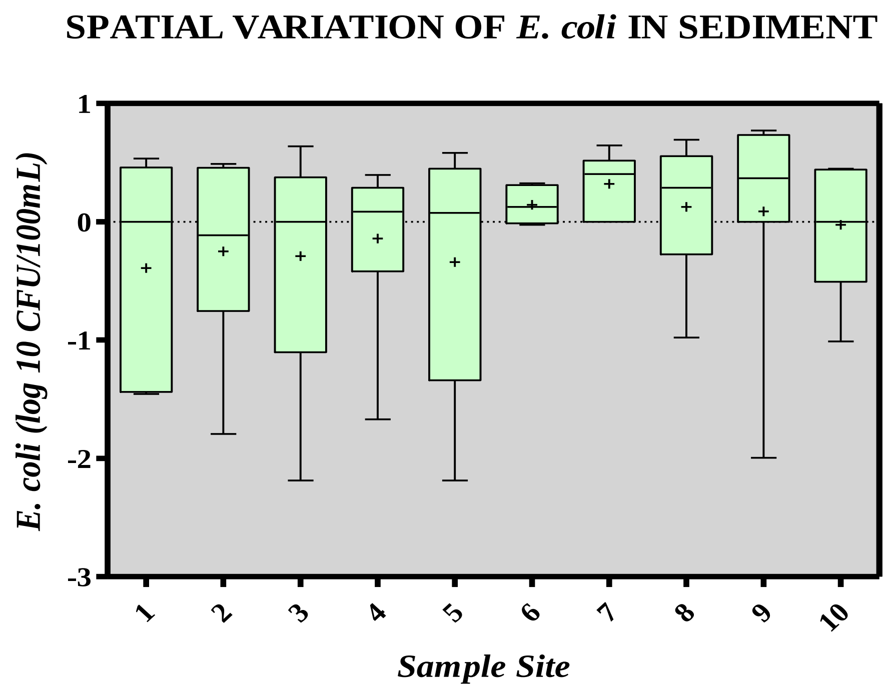
As shown in Table 9 and Figure 8, there is a variation found among *E. coli* concentrations in water across sample dates for all sample sites, with the lowest mean *E. coli* concentration on 7/17/13 (1.06 $\log_{10}$ CFU/100mL) and the highest mean *E. coli* concentration found on 9/11/13 (2.72 $\log_{10}$ CFU/100mL). Paired samples t-test determined that the differences in mean *E. coli* concentrations in water between these two sample dates were statistically significant ($p = .003$; Table 10a).

Table 9: Univariate analyses of selected water quality variables sampled from the Utoy Creek by date, Atlanta, Georgia, 2013.

	Range	Minimum	Maximum	Mean
E. coli* in water by date				
6/19/2013	2.01	0.22	2.23	1.22
6/26/2013	2.48	0.00	2.48	1.80
7/17/2013	2.75	-0.08	2.67	1.06
7/24/2013	2.19	0.15	2.34	2.01
8/8/2013	0.09	2.56	2.65	2.60
8/21/2013	0.02	2.62	2.63	2.63
9/11/2013	0.25	2.59	2.85	2.72
***E. coli* in sediment by date**				
6/19/2013	2.47	-1.99	0.48	-0.53
6/26/2013	1.05	-0.41	0.64	0.23
7/17/2013	2.96	-2.19	0.77	-0.75
7/24/2013	0.58	0.00	0.58	0.10
8/8/2013	0.33	0.32	0.65	0.44
8/21/2013	0.29	0.45	0.74	0.56
9/11/2013	0.51	-0.02	0.49	0.26
Turbidity by date**				
6/19/2013				
6/26/2013				
7/17/2013				
7/24/2013				
8/8/2013	1.96	6.3	8.26	7.26
8/21/2013	0.04	4.81	4.85	4.84
9/11/2013	0.77	1.98	2.75	2.41

* All *E. coli* concentrations in water are presented as log 10 CFU/100mL and log 10 CFU/gr in sediment
**Turbidity values are presented as NTU

Figure 9: Spatial Variation of *E. coli* among Utoy Creek Sediment Samples



As shown in Table 8 and Figure 9, the mean *E. coli* concentrations in sediment across sites for all sampling dates were similar. Further analysis revealed that there were no statistically significant differences in mean *E. coli* concentrations in sediment between sample sites (p = .203; Table 10b).

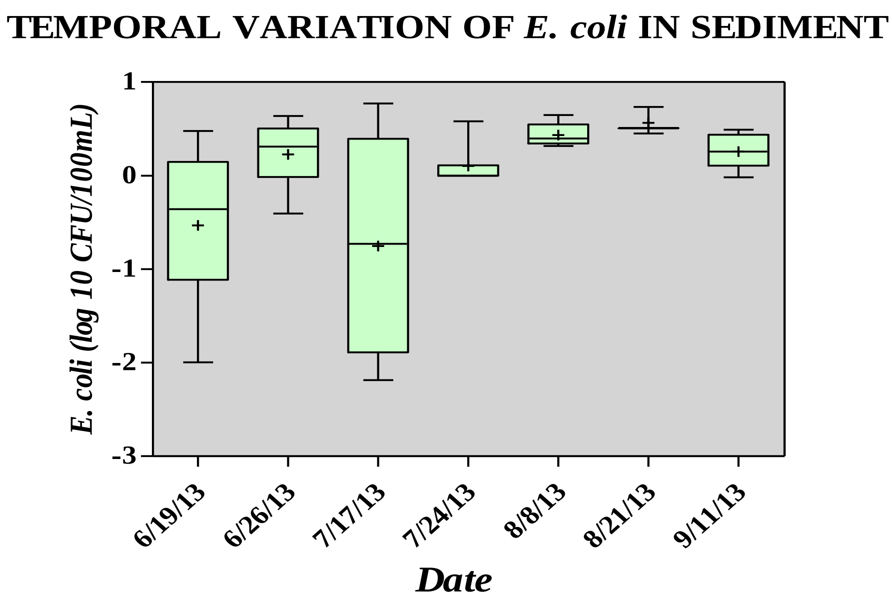
Table 10b: Determination of statistical significance between samples with the highest and lowest mean values of mean *E. coli* concentrations among sediment samples from the Utoy Creek, Atlanta, Georgia, 2013.

	Mean Values		95% Confidence Interval of the Mean Difference	P-value*
	Lowest	Highest		
Mean concentrations of *E. coli* in sediment**				
Between sites 1 (lowest) and 7 (highest)	-0.39	0.26	-1.830 - .5343	.203
Between sample dates 7/17/13 (lowest) and 8/21/13 (highest)	0.49	0.56	-.9016 - .7497	.731

* Pearson's correlation coefficient with level of significance reported as p < .05

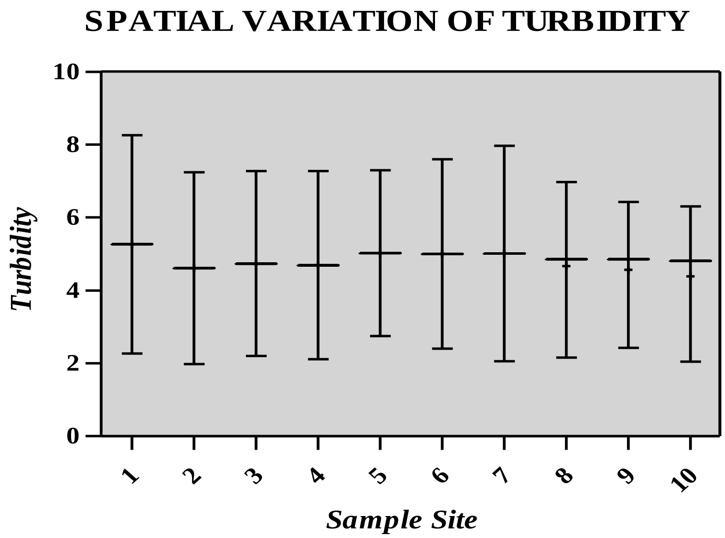
** *E. coli* concentrations in log 10 CFU/gr for sediment

Figure 10: Temporal Variation in *E. coli* in Utoy Creek Sediment Samples



According to Table 9 and Figure 10, the variability in mean *E. coli* concentrations in sediment exist among samples dates across all sample sites is apparent; however, no statistically significant differences were found among the mean *E. coli* concentrations in sediment samples (p = .731; Tables 10b).

Figure 11: Spatial Variation of Turbidity among Utoy Creek Water Samples



Based on data from Table 8 and Figure 11, the mean turbidity values across sites for all sampling dates were similar. Further analysis revealed that there were no statistically significant differences in mean turbidity values between sample sites (p = .429; Table 10c).

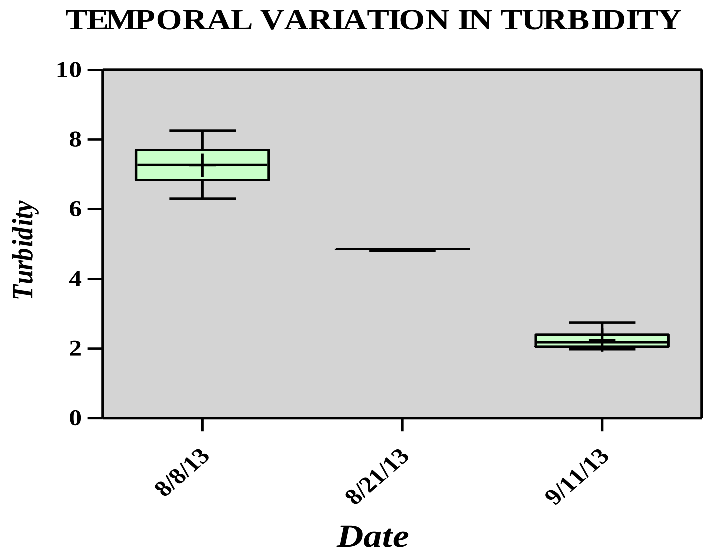
Table 10c: Determination of statistical significance between samples with the highest and lowest mean values of turbidty among water samples from the Utoy Creek, Atlanta, Georgia, 2013.

	Mean Values		95% Confidence Interval of the Mean Difference	P-value*
	Lowest	Highest		
Mean values for Turbidity**				
Between sites 10 (lowest) and 1 (highest)	4.18	5.27	-9.964 - 12.14	.429
Between sample dates 9/11/13 (lowest) and 8/8/13 (highest)	2.24	7.26	4.559 - 5.481	< .0001

* Pearson's correlation coefficient with level of significance reported as p < .05

** Turbidity values in NTU

Figure 12: Temporal Variation of Turbidity among Utoy Creek Water Samples



As shown in Table 9 and Figure 12, there is a variation found among turbidity values across sample dates for all sample sites, with the lowest mean turbidity value on 9/11/13 (2.24 NTU) and the highest mean turbidity value found on 8/8/13 (7.26 NTU). Paired samples t-test determined that the differences in mean turbidity values between these two sample dates were statistically significant ($p < .0001$; Table 10c).

Table 11: Analysis of Pearson's correlations between *E. coli* in water and selected water quality variables sampled from the Utoy Creek, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
***E. coli* in water and Turbidity**		
Site 1	-1.000	< .0001
Site 2	-1.000	< .0001
Site 3	-1.000	< .0001
Site 4	-1.000	< .0001
Site 5	-1.000	< .0001
Site 6	-1.000	< .0001
Site 7	-1.000	< .0001
Site 8	-0.856	< .0001
Site 9	-0.971	.154
Site 10	-0.925	.248
***E.coli* in water and Rainfall**		
Site 1	0.048	.929
Site 2	0.255	.625
Site 3	0.162	.76
Site 4	0.341	.508
Site 5	0.044	.934
Site 6	-0.763	.078
Site 7	-0.392	.443
Site 8	-0.007	.987
Site 9	-0.066	.887
Site 10	0.032	.952
***E. coli* in water and Rainfall (Day Before)**		
Site 1	-0.028	.957
Site 2	0.014	.979
Site 3	-0.055	.918
Site 4	0.326	.528
Site 5	-0.627	.182
Site 6	-0.164	.756
Site 7	-0.353	.493
Site 8	-0.613	.143
Site 9	-0.635	.126
Site 10	-0.579	.229
***E.coli* in water and *E.coli* in sediment**		
Site 1	0.551	.336
Site 2	-0.047	.93
Site 3	-0.236	.702
Site 4	-0.256	.624
Site 5	0.923	.025
Site 6	-0.818	.09
Site 7	0.264	.614
Site 8	-0.366	.476
Site 9	-0.138	.768
Site 10	0.748	.146

* Pearson's correlation coefficient with level of significance reported as $p < .05$

As shown in Table 11, *E. coli* in water is found to be negatively correlated with turbidity at sites 1-8 ($p < .05$) of the Utoy Creek. In addition, *E. coli* in water is positively correlated with *E. coli* in sediment at site 5 ($p = .025$) of the Utoy Creek.

Table 12: Analysis of Pearson's correlations between *E. coli* in sediment and selected water quality variables sampled from the Utoy Creek, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
***E.coli* in sediment and Turbidity**		
Site 1		
Site 2	-1.000	< .0001
Site 3		
Site 4	1.000	< .0001
Site 5	1.000	< .0001
Site 6		
Site 7	1.000	< .0001
Site 8	1.000	< .0001
Site 9	-0.094	.94
Site 10	1.000	< .0001
***E.coli* in sediment and Rainfall**		
Site 1	0.396	.509
Site 2	-0.302	.56
Site 3	0.248	.688
Site 4	-0.097	.854
Site 5	-0.893	.041
Site 6	0.776	.123
Site 7	0.059	.912
Site 8	0.133	.801
Site 9	0.325	.477
Site 10	0.460	.435
***E.coli* in sediment and Rainfall (Day Before)**		
Site 1	-0.912	.031
Site 2	-0.466	.351
Site 3	-0.860	.062
Site 4	-0.474	.343
Site 5	-0.636	.249
Site 6	0.209	.735
Site 7	0.077	.884
Site 8	-0.003	.996
Site 9	-0.057	.903
Site 10	-0.455	.441

* Pearson's correlation coefficient with level of significance reported as $p < .05$

According to data from Table 12, *E. coli* in sediment is found to be negatively correlated with turbidity at site 2 ($p < .0001$), but also positively associated with turbidity at sites 4, 5, 7, 8, and 10 ($p < .0001$) of the Utoy Creek. Also, *E. coli* in sediment is found to be negatively correlated with rainfall the day of sampling at site 5 ($p = .041$), as well as with rainfall the day before sampling at site 1 ($p = .031$).

Table 13: Analysis of Pearson's correlations between MS2 and selected water quality variables sampled from the Utoy Creek, Atlanta, Georgia, 2013.

	Pearson's R	P-value*
MS2 and Turbidity**		
Site 1		
Site 2		
Site 3		
Site 4	1.000	< .0001
Site 5	1.000	< .0001
Site 6	1.000	< .0001
Site 7	1.000	< .0001
Site 8	0.830	.377
Site 9	0.800	.41
Site 10		
MS2 and Rainfall		
Site 1		
Site 2		
Site 3		
Site 4	0.999	.028
Site 5	0.999	.028
Site 6	0.999	.028
Site 7	0.999	.028
Site 8	-0.242	.758
Site 9	-0.242	.758
Site 10		
MS2 and Rainfall (Day Before)		
Site 1		
Site 2		
Site 3		
Site 4	1.000	.003
Site 5	1.000	.003
Site 6	1.000	.003
Site 7	1.000	.003
Site 8	1.000	< .0001
Site 9	1.000	< .0001
Site 10		
MS2 and *E.coli* in water		
Site 1		
Site 2		
Site 3		
Site 4	0.487	.676
Site 5	0.151	.903
Site 6	0.380	.752
Site 7	-0.500	.667
Site 8	0.192	.808
Site 9	-0.047	.953
Site 10		
MS2 and *E.coli* in sediment		
Site 1		
Site 2		
Site 3		
Site 4	0.959	.183
Site 5	-0.028	.982
Site 6		
Site 7	0.801	.408
Site 8		
Site 9	-0.045	.955
Site 10		

* Pearson's correlation coefficient with level of significance reported as $p < .05$
** Missing correlations are due to a variable being counted as a constant during statistical analyses

Based on the results from Table 13, MS2 was found to be positively correlated with the following water quality parameters of the Utoy Creek: turbidity at sites 4-7 ($p < .0001$), rainfall the day of sampling at sites 4-7 ($p = .028$), and rainfall the day before sampling at sites 4-9 ($p < .05$).

Table 14: Determination of spatial and temporal variation of mean *E. coli* concentrations based on the presence or absence of MS2 among water samples from the Utoy Creek, Atlanta, Georgia, 2013.

	Mean Values		95% Confidence Interval of the Mean Difference	P-value*
	MS2 Present	MS2 Absent		
Mean concentrations of *E. coli* in water by site**				
Site 1				
Site 2				
Site 3				
Site 4	1.38	2.57	-28.28 - 25.91	.676
Site 5	2.48	2.56	-7.180 - 7.009	.903
Site 6	2.42	2.58	-5.115 - 4.794	.752
Site 7	1.30	0.00	-27.25 - 29.84	.667
Site 8	2.55	2.65	-1.627 - 1.431	.808
Site 9	2.59	2.58	-1.194 - 1.231	.953
Site 10				
Mean concentrations of *E.coli* in sediment by site				
Site 1				
Site 2				
Site 3				
Site 4	0.06	0.40	-1.614 - .9364	.183
Site 5	0.33	0.32	-5.575 - 5.600	.982
Site 6				
Site 7	0.19	0.65	-4.739 - 3.835	.408
Site 8				
Site 9	0.40	0.37	-1.184 - 1.869	.955
Site 10				
Mean concentrations of *E.coli* in water by date				
6/19/2013				
6/26/2013				
7/17/2013				
7/24/2013				
8/8/2013	2.61	2.59	-.0245 - .0639	.334
8/21/2013				
9/11/2013				
Mean concentrations of *E.coli* in sediment by date				
6/19/2013				
6/26/2013				
7/17/2013				
7/24/2013				
8/8/2013	0.45	0.43	-.5090 - .5379	.936
8/21/2013				
9/11/2013				

* Pearson's correlation coefficient with level of significance reported as $p < .05$

** Missing correlations are due to MS2 being counted as a constant during statistical analyses

As shown in Table 14, mean concentrations of *E. coli* in both water and sediment were similar for sites across all sample dates, regardless if MS2 was present or absent. Furthermore, , mean concentrations of *E. coli* in both water and sediment were similar for sample dates across all sites, regardless if MS2 was present or absent. No statistically significant differences in mean *E. coli* levels were found between any sample site or sample date when comparing the presence or absence of MS2 at each sample site ($p > .05$).

CHAPTER V

DISCUSSION

5.1 Importance of study

Due to Atlanta's dependence on the Chattahoochee River and the Utoy Creek, the importance of monitoring and maintaining the integrity of these surface waters could not stressed enough. With the growing population, not only was there an overload of sanitary sewage in the system, but also a tremendous increase in the amount stormwater as a result of increased impervious cover. To overcome the poor water quality for the health of the consumers, the federal government instituted measures to protect the river's water quality by defining and monitoring definitive water quality standards. After failing to meet these standards, the city of Atlanta had to make further changes to ensure the appropriate treatment of wastewater discharge being released into the Chattahoochee River and Utoy Creek. Currently, due to growth in population of the surrounding metro Atlanta areas, more potential stress from stormwater runoff and nonpoint source loading are affecting the Chattahoochee River. This issue was exacerbated during 2013 as Atlanta experienced a record-breaking amount of rainfall, further emphasizing the necessity of this research since previous studies have found a degredation in water quality and increased pollutant load as a result of recent flood events. Finally, this research opportunity is increasingly important since few investigations have been published concerning the water quality of the Chattahoochee River and Utoy Creek

5.2 Major Findings

This study found a significant temporal variation in mean *E. coli* concentrations among Chattahoochee water samples between sample dates 5/10/13 and 8/13/13. Moreover, DO and turbidity also had significant temporal differences in mean values. In fact, the lowest mean DO value and the highest mean turbidity value both occurred on the date with the highest mean *E. coli* concentrations. Also, a significant positive correlation was found between *E. coli* in sediment samples from the Utoy Creek and turbidity. These findings are found to be consistent with the literature. Chase et al. found significant positive correlations between *E. coli* and turbidity (Chase et al., 2012). Fong et al. concluded that the most contaminated surface water sample site experienced high turbidity (Fong et al., 2005). A previous study on the Chattahoochee River in Atlanta not only found that *E. coli* density in samples was strongly related to turbidity, but that *E. coli* density and turbidity were linearly related (Lawrence, 2012). Moreover, Cheng et al. proved that positive increases in DO promotes decay of *E. coli*, while Karn et al. found trends between increased total coliforms and decreases in DO (Cheng et al., 2013) (Karn & Harada, 2001). Although this study did not find significant correlations between rainfall and *E. coli*, it is noteworthy to mention that the highest accumulated precipitation occurred on 8/12/13, and that Dorner et al., as well as Astrom et al., found significant positive correlations between turbidity and wet-weather events (Astrom et al., 2007; Dorner et al., 2007).

No significant spatial variation was found in *E. coli* concentrations among Chattahoochee water samples. In addition, effluent from the two outfalls did not significantly increase the mean *E. coli* concentrations downstream. The conclusions of Astrom et al., Debels et al., and Ferreira et al. point to decreasing water quality downstream of wastewater discharges (Astrom et al., 2009; Debels et al., 2005; Ferreira et al., 2010). The lack of significant increases in *E. coli* concentrations downstream of the effluent discharges along the Chattahoochee suggest that improvements in the quality of effluent being assimilated into the Chattahoochee River reduce the impact on bacterial contamination (EPD, 1997).

Bacteriophage MS2, a potential indicator of the presence of human viruses in water, was not found to be significantly correlated with *E. coli* among water samples from either the Chattahoochee River or the Utoy Creek. Moreover, mean *E. coli* concentrations were not significantly influenced by the presence of MS2 at sample sites on any sample date. These findings were consistent with a previous study conducted by Luther et al. who found that FRNA coliphages were found in significant concentrations although fecal indicator bacteria was drastically reduced. Luther et al. also concluded that monitoring for fecal indicator bacteria may not adequately detect viral contamination (Luther & Fujioka, 2004).

Significant spatial variation in *E. coli* concentrations among water samples from the Utoy Creek occurred between sites 7 and 2, as well as temporal variation between sample dates 7/17/13 and 9/11/13. The only significant correlation found was between *E. coli* and turbidity; however, the correlation was negative. This may be due to small sample size since turbidity was only sampled on three of the seven sample dates.

This study found no significant spatial or temporal variation in *E. coli* concentrations among sediment samples from the Utoy Creek. Moreover, mean *E. coli* concentrations among sediment samples was not significantly correlated with mean *E. coli* concentrations among water samples. These findings could be consistent with literature since there are differing results on the influencing factor of fecal indicator bacteria within sediment and the overlying surface water quality. For instance, Casteel et al. only found detectable levels of *E. coli* in 7% and 4% of the same sediment sample site over time, suggesting that *E. coli* may not be a suitable indicator for detecting contamination in soil (Casteel et al., 2006). Ouattara et al. concluded that potential resuspended *E. coli* represented only 1% of contamination within the water column at 6 of 12 sites, and only 1-10% at 4 of 12 sites, suggesting that *E. coli* in sediment may not significantly contribute to river water contamination during resuspension (Ouattara et al., 2011).

Finally, significant positive correlations were found between MS2 and turbidity, rainfall the day of sampling, and rainfall the day before sampling. These findings are all consistent with previous literature. Dorner et al. discovered that peaks in pathogen numbers preceded peaks in fecal indicator bacteria and turbidity (Dorner et al., 2007). Brion et al. recovered F+ coliphages from 75% of wet weather samples (Brion et al., 2002). Astrom et al. suggested that turbidity and precipitation should be complementary monitoring tools for surface water contamination (Astrom et al., 2007).

In summary, the findings of this investigation suggest that the presence of *E. coli* and MS2 within the Chattahoochee River and Utoy Creek are potentially a result of nonpoint sources of pollution, rather than point sources of contamination such as sewage outfalls. Second, the monitoring of DO and turbidity could be useful and appropriate indicators for detecting *E. coli* contamination; whereas the monitoring of turbidity and rainfall could be used as indicators for detecting MS2 contamination. Finally, since no significant correlation was found between MS2 and mean *E. coli* concentrations, we cannot conclude that MS2 is indicative of *E. coli* contamination.

5.3 Strengths and Limitation

Strengths

There is currently no published research investigating the current water quality, spatiotemporal variation of *E. coli* and MS2, or correlation between these microbial and pathogenic indicators with certain water quality parameters (such as DO, turbidity, riverflow, and rainfall) of the Chattahoochee and Utoy Creek. Moreover, this timing of this research occurred during a period of record-breaking rainfall.

Limitations

For the Utoy Creek, some plates had colony counts that were too numerous to count, which are counted as zero in the data. This occurred for all samples sites for both water and sediment at Utoy Creek, as well as two sample dates for water (6/26/13 and 8/8/13) and six sample dates for sediment (6/19/13, 6/26/13, 7/17/13, 7/24/13, 8/8/13, and 9/11/13). Also, we could not conclude that any contamination in the sediment was not influenced by the overlying water contamination. Next, contamination of host inhibited MS2 data for three of the seven sample dates of the Utoy Creek (6/19/13, 6/26/13, and 7/17/13), which could have underestimated the correlations between *E. coli* concentrations in both the water and sediment samples. Finally, if MS2 data were the same for a specific site or specific date (all present or all absent), no measures of association were computed because it was considered a constant variable.

5.4 Future Research

First, to ensure that the water quality of the Chattahoochee River and Utoy Creek are within federal and state standards, the monitoring of these surface waters should continue. Second, future research should determine sources of contamination, especially those located upstream of the Chattahoochee River and Utoy Creek, perhaps through the collection of stormwater samples to determine the specific impact that stormwater has on the water quality of the river and creek. Thirdly, further investigation of the Utoy Creek surface water samples should be conducted to determine possible pathways of contamination between the proposed water quality parameters and the spatiotemporal variations in mean *E. coli* concentrations. Finally, to determine the usefulness of monitoring the presence of MS2, further investigation into the correlation between MS2 and other enteric viruses is strongly encouraged.

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APPENDIX A- TABLES

Table 15: Industrial Facilities with a General Stormwater National Pollutant Discharge Elimination System (NPDES) Permit*

Facility Name	Permit Number	Receiving Watersheds and Streams
Atlanta	GAS000100	Chattahoochee & Flint Watersheds
Abrams Fixture Corporation	01011	Utoy Creek
All American Gourmet Company	00076	Utoy Creek
Barton Brands of Georgia	00064	North Utoy Creek
Cascade Road Landfill	02959	Utoy Creek
Central Metals Company	01052	Utoy Creek
Central of GA Railroad Co.	00800	Utoy Creek
City of Atlanta- Utoy Creek WRC	02833	Utoy Creek
Coca-Cola USA - Beverage Base Plant	01237	Utoy Creek
Continental Plastic Containers #430	03899	Utoy Creek
Crown Cork & Seal Company, Inc.	00606	Utoy Creek
Dispersion, Inc	00524	Utoy Creek
Federal Express QEFA	02925	Utoy Creek
Foamex, LP	02934	Utoy Creek
Fort McPherson	00766	South Utoy Creek
Kor-Chem Incorporated	03817	Utoy Creek
Lester Laboratories, Inc.	00162	Utoy Creek
Metalplate Galvanizing, L.P.	01259	Utoy Creek
Metro Alloys, Inc	03048	Utoy Creek
Metro Alloys, Inc	03855	South Utoy River
Norfolk Southern - East Point Yard	00793	Utoy Creek
Selig Chemical Industries	00575	Utoy Creek
Southern Wood Piedmont Company	00269	Utoy Creek
Stanley Bostitch	00158	Utoy Creek
Sun Chemical Corporation	02678	Utoy Creek
Tecpro Corporation	00409	Utoy Creek
Tenneco Packaging - Hexacomb	02691	Utoy Creek
U.S.P.S. Vehicle Maintenance Facility	02409	North Utoy Creek
Utoy Creek WRC	03828	Utoy Creek
Vinings Industries	01911	Utoy Creek
Wilbert Burial Vault Company	00115	Utoy Creek
William C. Meredith Company, Inc.	00872	South Utoy Creek

* (EPA, 2003)

Table 16: Non-transformed data of water samples from the Chattahoochee River, Atlanta, Georgia, 2013.

E. coli*

Site	Date	4/17/2013	5/10/13	7/29/13	8/13/13	9/5/13	9/18/13	10/3/13
	Site 1	175.00	43.64	424.17	563.33	164.17	194.17	96.67
	Site 2	193.33	63.18	527.50	603.33	193.33	199.17	90.00
	Site 3	169.17	76.36	437.27	520.00	177.50	190.00	66.67
	Camp Creek Outfall		33.64	3.33	1.67	0.83	25.00	
	Site 4	191.67	86.36	460.83	571.67	168.33	169.17	69.17
	Site 5	183.33	70.91	375.83	613.33	192.50	263.33	84.17
	Site 6	166.67	69.55	201.67	596.67	158.33	243.33	93.33
	Site 7	204.17	12.27	130.83	553.33	181.67	261.67	97.5
	Site 8	168.33	68.18	87.50	503.33	204.17	320.83	95.83
	Site 9	105.83	64.09	69.17	686.67	179.17	284.17	85.83
	Site 10	159.17	60.00	73.33	540.00	209.17	348.33	100.83
	Site 11	140.83	72.73	81.67	446.67	224.17	253.33	95.00
	Douglas County Outfall		71.82	30.83	489.17	130.83	327.50	95.833
	Site 12	135.00	69.55	60.00	483.33	190.83	309.17	103.33
	Site 13	152.50	65.45	45.83	436.67	204.17	268.33	93.33
	Site 14	61.67	66.82	51.67	543.33	218.33	215.83	100.00
	Site 15	132.50	75.45	55.83	360.00	219.17	283.33	90.83

MS2**

	Site	4/17/2013	5/10/13	7/29/13	8/13/13	9/5/13	9/18/13	10/3/13
	Site 1	1	1	1	1	1	1	1
	Site 2	1	1	1	1	1	1	1
	Site 3	1	1	1	1	0	1	0
	Camp Creek Outfall		1	0	0		0	
	Site 4	1	1	1	1	1	0	1
	Site 5	1	1	0	1	0	1	0
	Site 6	0	1	1	1	0	0	0
	Site 7	1	1	1	1	1	0	1
	Site 8	1	1	1	1	0	0	0
	Site 9	1	1	1	1	0	0	0
	Site 10	0	1	1	1	0	0	0
	Site 11	0	1	1	1	1	0	0
	Douglas County Outfall		1	1	1		0	0
	Site 12	1	1	1	1	0	1	0
	Site 13	1	1	1	1	0	0	1
	Site 14	1	1	1	1	0	0	1
	Site 15	1	1	1	1	0	0	1

* All *E. coli* concentrations are presented as CFU/100mL

**MS2 of 0 = plaque absent; MS2 of 1 = plaque present

Table 17: Non-transformed data of water and sediment samples from the Utoy Creek, Atlanta, Georgia, 2013.

E. coli* in water								
	Date	6/19/13	6/26/13	7/17/13	7/24/13	8/8/13	8/21/13	9/11/13
Site								
	Site 1	7.50	140.83	252.50	189.17	396.67		490.83
	Site 2	6.67	304.29	470.00	125.83	398.33		561.67
	Site 3	1.67	179.17	262.50	162.50	414.17		496.67
	Site 4	6.67	233.33	368.33	1.40	367.50		405.83
	Site 5	21.67	244.17	0.00	143.33	366.67		632.5
	Site 6	57.50	0.00	0.00	157.50	382.50		444.17
	Site 7	20.00	0.00	0.00	148.33	416.67		392.5
	Site 8	169.17	228.33	0.00	163.33	448.33	430.83	649.17
	Site 9	128.33	148.33	0.83	218.33	376.67	415.83	669.17
	Site 10	5.83		4.17	183.33	432.50	423.33	705.83
E. coli* sediment*								
	Site 1	0.04	3.43	0.03	0.00			2.41
	Site 2	0.59	0.39	0.02	0.00	2.79		3.08
	Site 3	1.29	4.35	0.01	0.00			0.96
	Site 4	1.78	1.14	0.02	0.00	2.49		1.31
	Site 5	0.32		0.01	3.82	2.07		1.19
	Site 6	0.94	2.12	1.96	0.00			1.34
	Site 7	2.99	2.60	0.00	0.00	4.43		2.45
	Site 8	0.10	0.92	4.94	2.77		3.21	1.36
	Site 9	0.01	1.97	5.90	0.00	2.33	5.43	2.82
	Site 10	0.10		0.00	0.00		2.82	2.72
MS2***								
	Site 1				1	1		1
	Site 2				1	1		1
	Site 3				1	1		1
	Site 4				1	0		1
	Site 5				1	0		1
	Site 6				1	0		1
	Site 7				1	0		1
	Site 8				1	0	1	1
	Site 9				1	0	1	1
	Site 10				1	1	1	1

* All *E. coli* concentrations in water are presented as CFU/100mL

** All *E. coli* concentrations in sediment are presented as CFU/gr

***MS2 of 0 = plaque absent; MS2 of 1 = plaque present

Table 18: Selected water quality variables of water samples from the Chattahoochee River, Atlanta, Georgia, 2013.

Dissolved Oxygen								
	Date	4/17/2013	5/10/13	7/29/13	8/13/13	9/5/13	9/18/13	10/3/13
Site								
	Site 1	8.50		7.60	6.60	8.70	8.70	8.50
	Site 2	8.44		7.50	6.50	8.50	8.60	8.40
	Site 3	8.39		7.60	6.50	8.50	8.50	8.30
	Site 4	8.39		7.60	6.60	8.50	8.40	8.40
	Site 5	8.37		7.40	6.60	8.30	8.40	8.30
	Site 6	8.36		7.60	6.60	8.20	8.20	8.30
	Site 7	8.33		7.60	6.70	8.40	8.20	8.20
	Site 8	8.34		7.80	6.60	8.30	8.20	8.30
	Site 9	8.32		7.70	6.60	8.20	8.10	8.20
	Site 10	8.28		7.70	6.50	8.20	8.10	8.10
	Site 11	8.28		7.60	6.40	8.10	8.10	7.10
	Site 12	8.25		7.60	6.20	8.30	8.00	8.10
	Site 13	8.17		7.70	6.20	8.20	7.90	8.20
	Site 14	8.11		7.50	6.20	8.20	7.80	8.00
	Site 15	8.09		7.50	6.30	8.30	7.90	8.20
Turbidity								
	Site 1			15.90	20.40	5.31	4.43	2.17
	Site 2			39.50	58.60	6.29	3.77	2.10
	Site 3			31.70	24.60	7.84	3.28	2.20
	Camp Creek Outfall			1.21	0.60	0.19	1.50	
	Site 4			29.30	24.00	6.20	4.40	2.22
	Site 5			24.90	25.30	6.65	5.26	2.45
	Site 6			35.20	26.90	19.70	5.37	2.34
	Site 7			27.30	29.50	11.50	3.39	2.23
	Site 8			14.20	47.20	6.78	4.26	2.44
	Site 9			18.20	42.30	9.25	5.84	2.55
	Site 10			8.25	33.10	8.26	5.81	2.43
	Site 11			19.70	32.40	7.46	5.63	2.64
	Douglas County Outfall				10.10	30.90	3.91	2.83
	Site 12			19.00	32.30	11.80	6.03	2.60
	Site 13			14.90	34.00	25.00	4.31	2.75
	Site 14			7.66	34.50	6.94	4.24	2.82
	Site 15			9.34	34.70	7.06	7.81	2.97
Rainfall, in.*								
	All Sites	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rainfall, in. (day before)*								
	All Sites	0.00	0.00	0.00	0.67	0.00	0.00	0.00
Riverflow, ft3/s**								
	All Sites	2030	8270	1080	4130	6040	4010	2260

* (Georgia Automated Environmental Monitoring Network, 2013)

**(USGS, 2013)

Table 19: Selected water quality parameters of water samples from the Utoy Creek, Atlanta, Georgia, 2013.

Turbidity							
Date / **Site**	6/19/13	6/26/13	7/17/13	7/24/13	8/8/13	8/21/13	9/11/13
Site 1					8.26		2.27
Site 2					7.24		1.98
Site 3					7.27		2.20
Site 4					7.27		2.11
Site 5					7.30		2.75
Site 6					7.60		2.40
Site 7					7.97		2.06
Site 8					6.97	4.85	2.16
Site 9					6.43	4.85	2.43
Site 10					6.30	4.81	2.05
Rainfall, in.*							
All Sites	0.000	0.410	0.100	0.001	0.020	0.200	0.000
Rainfall, in. (day before)*							
All Sites	0.290	0.000	0.560	0.003	0.500	0.000	0.000

* (Georgia Automated Environmental Monitoring Network, 2013)

Table 20: Distances between samples points along the Chattahoochee River and Utoy Creek, Atlanta, Georgia, 2013.

Chattahoochee River

Sites	Distance, mi.*
1-2	0.99
2-3	0.64
3- Camp Creek Outfall	0.46
3-4	1.04
4-5	0.90
5-6	0.96
6-7	0.98
7-8	1.01
8-9	0.99
9-10	0.93
10-11	0.80
11- Douglas County Outfall	0.16
11-12	0.79
12-13	0.97
13-14	0.98
14-15	0.93
1-15	11.64

Utoy Creek

Sites	Distance, sq. ft.*
10-9	70.98
9-8	31.60
8-1	0.10 mi.
1-2	354.03
2-3	80.58
3-4	31.26
4-5	23.04
5-6	302.45
6-7	40.23
10-7	0.27 mi.

Utoy Creek to Chattahoochee River

Sites	Distance, mi.*
Utoy 10 - Chattahoochee 1	9.73

*As determined by Garmin BaseCamp version 4.5.2.0.

APPENDIX B- Chattahoochee River Figures

Figure 13. Temporal Variation in Rainfall at the Chattahoochee River the Day of Sampling

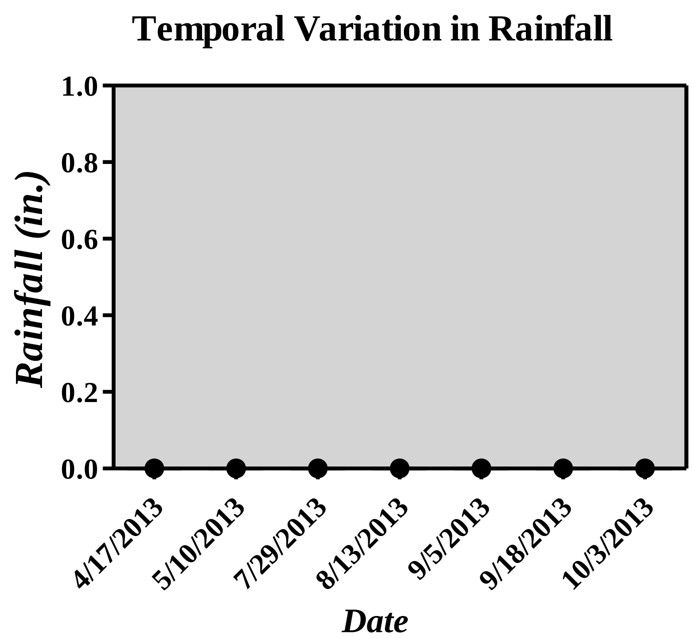


Figure 14. Temporal Variation in Rainfall at the Chattahoochee River the Day Before Sampling

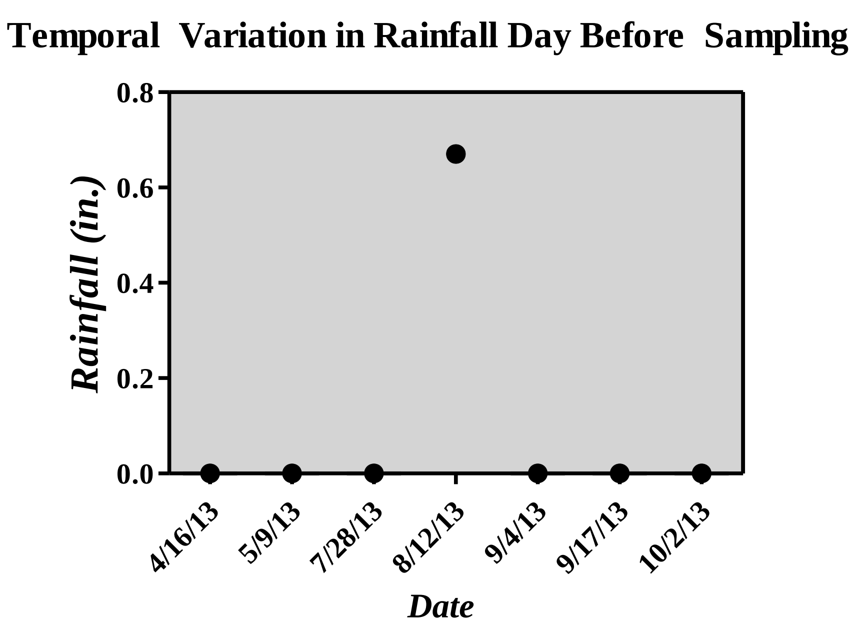


Figure 15. Temporal Variation in Riverflow of the Chattahoochee River

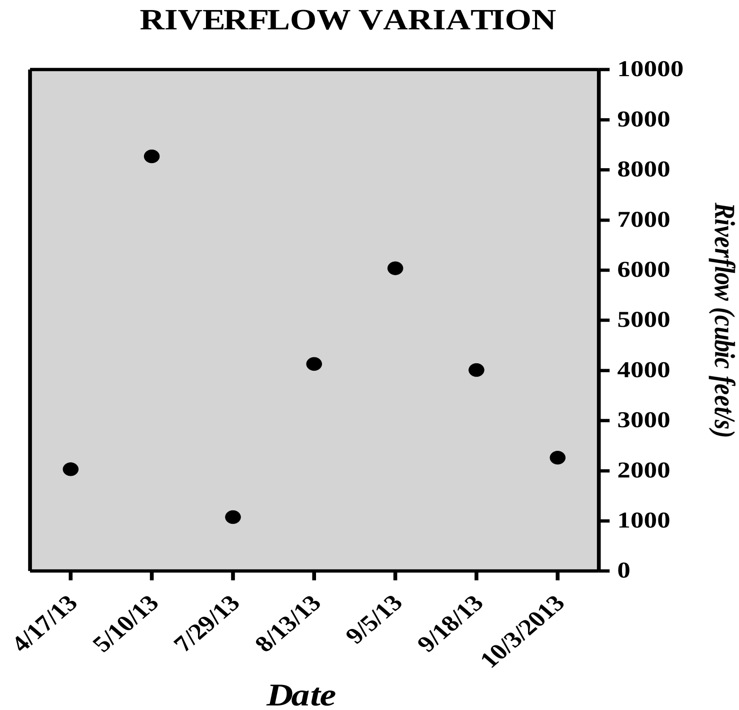


Figure 16. Temporal Variation in MS2 among Chattahoochee River Water Samples

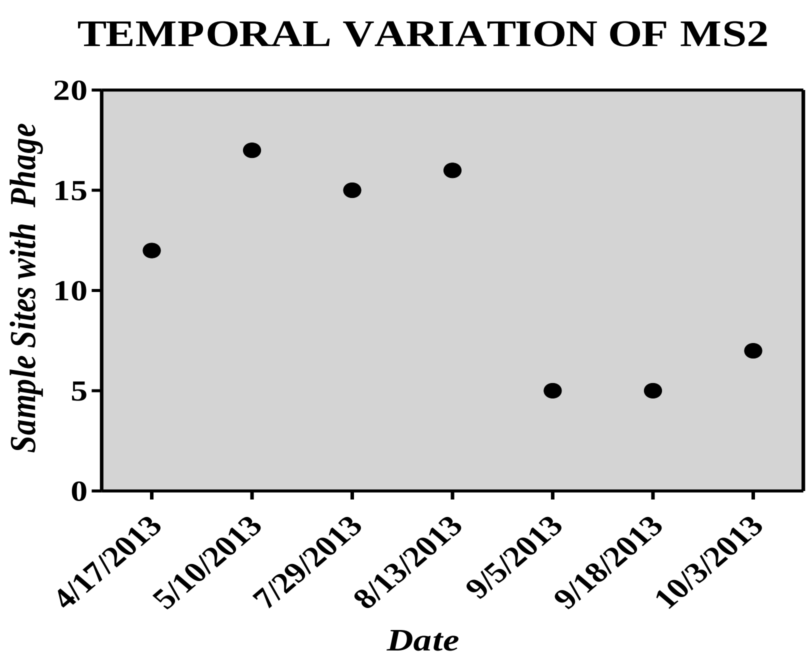
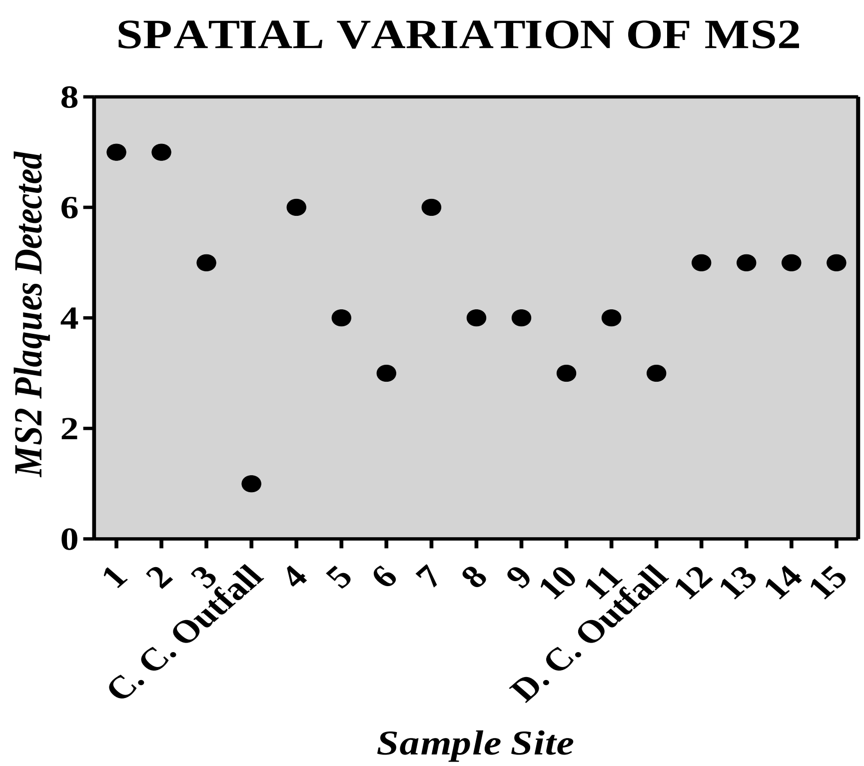


Figure 17. Spatial Variation in MS2 among Chattahoochee River Water Samples



APPENDIX C- Utoy Creek Figures

Figure 18: Temporal Variation in Rainfall at Utoy Creek the Day of Sampling

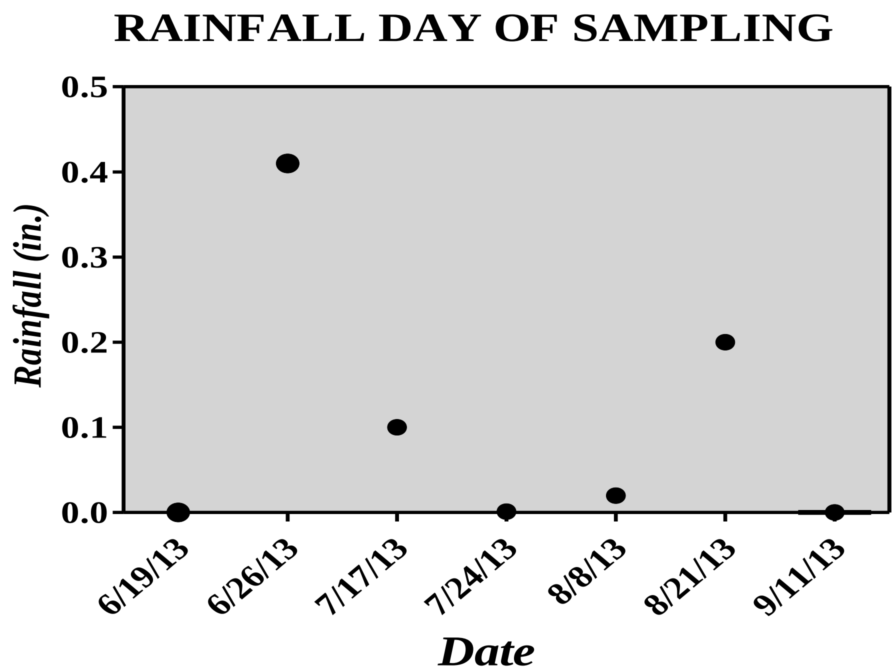


Figure 19: Temporal Variation in Rainfall at Utoy Creek the Day Before Sampling

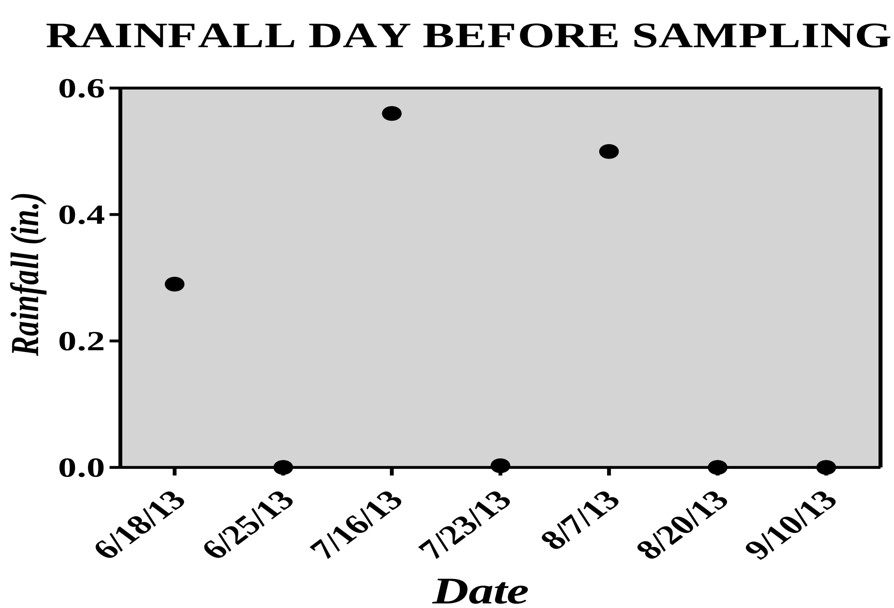


Figure 20: Temporal Variation in MS2 among Utoy Creek Water Samples

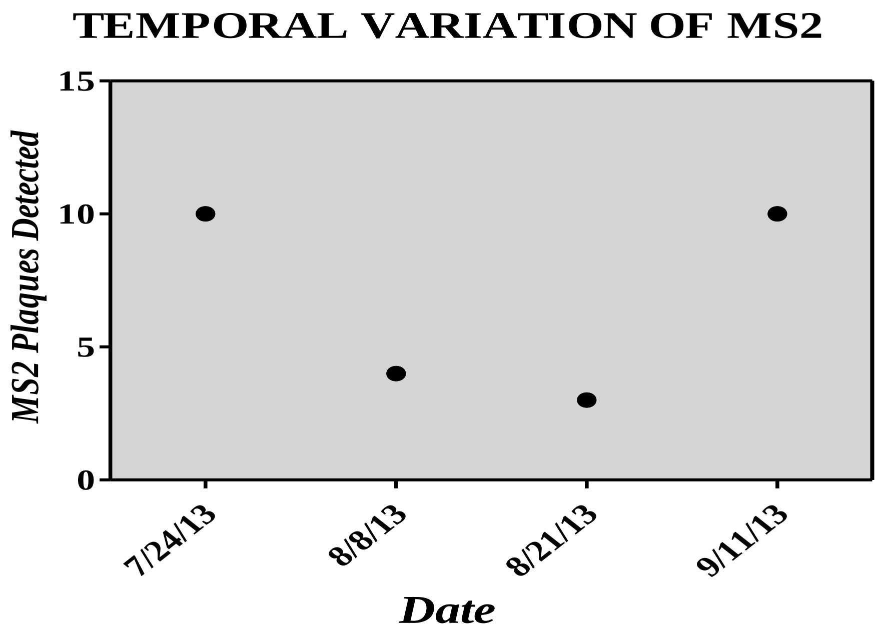


Figure 21: Spatial Variation in MS2 among Utoy Creek Water Samples